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MINI, MICRO, AND SWARMING UNMANNED AERIAL VEHICLES: A BASELINE STUDY

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Researcher: Patrick M. Miller

Project Manager: Malinda K. Goodrich

Federal Research Division
Library of Congress
Washington, D.C. 20540–4840
Tel: 202–707–3900
Fax: 202–707–3920
E-Mail: frds@loc.gov
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PREFACE

This report describes worldwide technological developments in miniature (mini) and micro unmanned aerial vehicles (UAVs), including swarming capabilities, flapping-wing, vertical-takeoff-and-landing, and tilt-rotor UAVs. In particular, the report describes trends in mini and micro UAV development, their technical capabilities and limitations, military and nonmilitary uses of UAVs, and the size of the worldwide UAV market. The appendix lists mini and micro UAVs produced in selected countries. The report draws on conference presentations, reports, journal articles, and manufacturer Web sites from around the world in English and other languages.

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KEY FINDINGS

- Unmanned aerial vehicles (UAVs) are popular because they are inexpensive, keep military personnel out of harm's way, and excel at dull, dangerous, and dirty missions. They are commonly used in intelligence, surveillance, and reconnaissance (ISR) missions; nuclear, biological, and radiological (NBR) detection; search and rescue in wartime and times of disaster; and the monitoring of electric and communications grids, agriculture, meteorology, traffic, borders, wild fires, natural disasters, etc.
- Miniaturization has led to smaller payloads of sensors, computers, communication devices, and power supplies that have allowed smaller UAVs to perform the the same functions as larger UAVs.
- UAVs can act as communications relays and assume the role of satellites; however, they do not yet have the advanced sensors, analytical ability, or onboard battle management and command and control capabilities equivalent to such systems as airborne warning and control systems (AWACs) and joint surveillance and target attack radar systems (JSTARs). To date, the use of UAVs in electronic warfare (EW) has been focused on larger UAVs, although miniaturized radio frequency components and small-form processor boards have the potential to drive the development of EW payloads for small UAVs.[1]
- Approximately 50 countries are developing and/or acquiring UAVs for their armed forces. The United States and Israel are the main innovators in the UAV field, but Australia, Belgium, China, France, Germany, Italy, Japan, the Netherlands, South Korea, and the United Kingdom are also active in UAV research, design, and production.
- UAV programs in China originally were based on U.S. and Russian designs, but today Chinese researchers are producing original research and their own designs for mini, micro, vertical-takeoff-and-landing (VTOL), and flapping-wing UAVs.
- UAV programs in Russia are behind those of the United States and other developed nations because of limited funding and the lack of modern designs. Russia's priorities for

[1] Anthony Finn, Kim Brown, and Tony Lindsay, "Miniature UAV's & Future Electronic Warfare," Government of Australia, Defence, Science and Technology Organisation (accessed October 1, 2006).
<http://www.aerosonde.com/downloads/Aerosonde_DSTO_EW.pdf>

UAV development include: defense against enemy UAVs; mini, micro, and nano platforms for UAVs; and swarming. Ukraine also produces a variety of UAVs.

- Mini UAVs (MUAVs) range in size from 15 to 30 centimeters to less than two meters in wingspan and are suitable for ISR, battlefield evaluation, NBR detection, communications relay, wiretapping, radar interference, and operations in cities and high-density population areas. Researchers are still working on onboard navigation and power systems that can fit into MUAVs.
- Micro UAVs (MAVs) have a wingspan of less than 30 centimeters and are used in battlefield reconnaissance, air monitoring, NBR detection, target identification, communications relay, and reconnoitering of building interiors. Miniaturization of the means of propulsion is the main stumbling block in MAV development. Researchers worldwide are investigating numerous alternatives to internal combustion engines, such as fuel cells, micro-turbo generators, thermo-photoelectric engines, lithium polymer cells, laser beams, and solar power. The smallest known micro UAV is the Black Widow, with a 23-centimeter wingspan and weight of 56 grams, developed by the U.S. company AeroVironment. Researchers in Belgium, China, France, and the United States are developing MAVs.
- Flapping-wing, tilt-rotor, and VTOL UAVs excel at hovering. Researchers in France, the Netherlands, the United Kingdom, and the United States are leaders in the flapping-wing UAV field; lesser players are China, Israel, and South Korea. Most research on tilt-rotor UAVs is being done in South Korea. VTOLs have not been miniaturized to a size much smaller than two meters in diameter and resemble either small helicopters or ducted fans. The United States, Israel, Italy, Japan, Singapore, South Korea, and the United Kingdom have designed and built VTOLs.
- Several UAVs can operate in a swarm, much as a flock of birds or bees in flight. Australia, Germany, Israel, the Netherlands, the United Kingdom, and the United States lead swarming research. China and South Korea are also involved in the field. Most swarming studies center on larger UAVs. The main technical obstacles to swarming UAV research include collision avoidance, path planning, and swarm search patterns.

INTRODUCTION

More than 40 countries worldwide are currently developing unmanned aerial vehicles (UAVs) for both military and civilian uses. UAVs are popular because they are inexpensive and keep military personnel out of harm's way. Excelling at dull, dangerous, and dirty missions, they have mostly been used for intelligence, surveillance, and reconnaissance (ISR) missions and as communications relays. UAV payloads consist of sensor arrays that transmit tactical information back to base in real time. They provide less expensive sensor platforms that incorporate greater loiter time than most manned aerial vehicles or satellites.

UAVs are also valuable in civilian applications, such as in agriculture, meteorology, public safety, and utilities management. For example, UAVs have been equipped to spray pesticides and take atmospheric measurements. Police departments have also purchased UAVs for use in search and rescue operations. Utility companies use them to monitor power lines, communications lines, and gas pipelines.

Advances in technologies, including miniaturization of sensors, computers, and communications devices, have led to improved mini and micro UAVs (MUAVs and MAVs, respectively). This, in turn, has allowed smaller UAVs to perform the same functions as larger UAVs. In addition, advances in collision avoidance and pathfinding have given rise to the possibility of swarms of UAVs acting together to carry out missions.

UAVs face some technological limitations. Unlike airborne warning and control systems (AWACs) and joint surveillance and target attack radar systems (JSTARs), UAVs do not yet have advanced sensors and analytical ability, nor do they have onboard battle management and command and control capabilities. These technologies may be miniaturized for future UAV payloads, but the expense of doing so may make UAVs less expendable than they are presently. At the cutting edge of current UAV research is advancing UAV autonomy through computer technology and artificial intelligence.

WORLDWIDE DEVELOPMENT OF UAVs

The United States was the first country to undertake UAV research and development. Dr. Samuel Pierpont Langley, Secretary of the Smithsonian Institution, launched the first winged UAV in 1896. The steam-powered, 14-kilogram air vehicle flew unguided for one minute over

the Potomac River to test early theories of flight.[2] In the 1930s, U.S. and British militaries for antiaircraft gunnery practice used radio-controlled airplanes. The Germans used *Vergeltungswaffe* (revenge weapon)–1, or V–1 rockets, as guided, flying bombs against the United Kingdom in World War II. In the 1950s, the Soviet Union's OKB Tupolev Experimental Design Bureau developed the TU–121 target drone, a precursor of the modern cruise missile.[3] Israel started working with UAVs in the early 1970s. The Israelis began by adding cameras to radio-controlled aircraft and later had great success using UAVs as decoys against enemy radar sites in the 1973 Yom Kippur War involving Israel, Egypt, and Syria. Israel also used UAVs to find enemy missile sites during 1982 operations in Lebanon.[4] In the 1970s, the United States used UAVs for reconnaissance missions in Vietnam. In the early 1990s, the United States employed UAVs in the Persian Gulf War and in the Balkans and started using U.S.-built Predators as munitions platforms.

Today approximately 50 countries are developing and/or acquiring UAVs for their armed forces. In Iraq nearly 700 UAVs are currently deployed.[5] The United States and Israel are the main innovators in the UAV field, but Australia, China, France, Germany, Italy, Japan, South Korea, and the United Kingdom are also active in UAV research, design, and production. In addition, organizations such as Hezbollah also have UAVs in their weapons arsenals and use them against their enemies.

United States

The United States has been developing UAVs since the 1930s, when they were first developed for use as target drones. By the 1970s, UAVs were used for reconnaissance in Vietnam and, in the 1980s, for tactical surveillance. The United States excels in all UAV types and technologies. For instance, General Atomics' Predator is a leading large UAV that features multiple mission capability. Companies such as AeroVironment, BAE Systems, USA, Honeywell, Northrup Grumman, and Sikorsky are some of the approximately two dozen U.S.

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2 Manjeet Singh Pardesi, "Unmanned Aerial Vehicles/Unmanned Combat Aerial Vehicles: Likely Missions and Challenges for the Policy-Relevant Future," *Air & Space Power Journal*, Fall 2005. <http://www.airpower.maxwell.af.mil/airchronicles/apj/apj05/fal05/pardesi.html>

3 Oleg Vladykin, "Unmanned Aerial Breakthrough," *MIGnews.com.ua* Web site, June 27, 2006 <http://mignews.com.ua/en/articles/213361.html> (accessed October 24, 2006).

4 "Spies that Fly," Public Broadcasting Service, November 2002. <http://www.pbs.org/wgbh/nova/spiesfly/uavs.html>

5 Vladykin.

manufacturers that design or produce large, mini, and micro UAVs, including ducted-fan vertical-takeoff-and-landing (VTOL) helicopters, and combat UAVs (UCAVs). The United States excels at all UAV system components, including sensors, avionics, airframes, and communications.[6] The world's smallest UAV is the Black Widow micro UAV developed by AeroVironment, which has a 23-centimeter wingspan and weighs 56 grams. In 2003 the U.S. military's budget for UAVs exceeded US$1 billion.[7]

The Middle East and Africa

Israel, another leader in UAV design and production, has been developing UAVs since the mid-1970s. Israeli companies are leaders in mini and micro UAVs and excel in the production of UAV sensor payloads and guidance systems. Approximately eight manufacturers design or build UAVs in Israel; Elbit Systems and IAI Malat are the two leading manufacturers of mini reconnaissance and surveillance UAVs. Israel produces medium-sized and small UAVs for use by its armed forces and for sales abroad to countries such as Australia, Singapore, and the United Kingdom.[8]

Israeli UAV companies in particular have aggressively pursued the international UAV market. Some companies are partnering with other companies in order to promote sales. Listed below are some recent examples of collaborations between Israeli UAV producers and partners in Australia, Canada, Poland, and Singapore:

- In December 2005, Australia purchased six Israeli Elbit Skylark IV systems (for a total of 18 UAVs) for operations in Iraq.[9]
- In May 2006, Israel's IAI partnered with Boeing Australia to outbid Australia's AAI/BAE Systems for sales of coast-monitoring UAVs to Australia's military. To help their bid, IAI and Boeing Australia proposed to "support the establishment of a UAV center of excellence in Queensland."[10]

[6] Alon Ben David, Robert Hewson, Damian Kemp, and Stephen Trimble, "Special Report: UAVs- Frontline Flyers," *Jane's Defence Weekly*, May 4, 2006.
[7] *Jane's Unmanned Aerial Vehicles and Targets.* <http://www.janes.com> (accessed 8/14/2006).
[8] David, Hewson, Kemp, and Trimble.
[9] Ian Kemp, "Controlling Drones at War," *Armada International* [Zurich], February/March 2006, 26.
[10] Tim Mahon, "Taking Off; Australian Industry Grows with UAV Needs," *C4ISR Journal*, June 1, 2006, 28 (via Lexis-Nexis).

- In June 2006, Elbit sold Skylark mini UAVs to the Canadian Army.[11]
- In September 2006, Elbit Systems signed a production and export agreement with Poland's Bumar Capital Group. Bumar will manufacture optical and measuring equipment for some Elbit UAVs and market Elbit UAVs to the Polish military.[12]
- Singapore's UAV industry currently is working with Israel to develop the Firefly UAV. According to a report, "This project will draw on the strengths of all major ST [Singapore Technologies] Engineering components. ST Aerospace is responsible for the UAV platform, ST Electronics for command and control systems, and ST Kinetics and ST Marine are integrating the system with vehicles and warships, respectively."[13] In the past, Singapore sold the Israeli Blue Horizon UAV to the Philippines.[14]

The Jordanian company Jordan Advanced Remote Systems also produces UAVs while the Lebanese political organization Hezbollah is known to possess larger UAVs.

South Africa firms have made a concerted effort to join the UAV market within the last 10 years and have succeeded in manufacturing UAVs with wingspans of 2.1 meters and longer. Advanced Technologies and Engineering (ATE) and Denel Aerospace Systems produce large reconnaissance UAVs such as ATE's 5.2-meter wingspan Vulture and Denel's 4.43-meter wingspan Seeker II. Denel's developmental Lark UAV has a wingspan of 2.1 meters and is designed to jam radar, attack air defenses, or conduct reconnaissance.[15] Denel also is designing a three-meter wingspan, high-speed UAV capable of Mach 0.85 and is working on a small, hand-launched UAV for the South African Department of Health that will deliver medicine to remote areas in South Africa.[16] In September 2006, Flight Global reported that ATE and Denel were discussing merging to become a single, national unmanned systems company.[17]

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[11] "Israel: Roundup of Defense Industries' Deals, Innovations 25 Jun–6 Jul 06," July 8, 2006 (via Open Resource Center GMP20060708740005). <https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_1019_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/6220970?action=advancedSearch&highlightQuery=eJzTcPcNMDIwMDMwN7AwNzEwMDDVBAAp3gP9&fileSize=42826>

[12] "Helicopter Suppliers Court Poland's Defence Industry," *Jane's Online*, September 14, 2006. <http://www.janes.com>

[13] "Singapore Sets the Pace," *Global Defence Review*, 2001. <http://www.global-defence.com/2001/RSpart3b.html>

[14] Manjeet Singh Pardesi, "UAVs/UCAVs-Missions, Challenges, and Strategic Implications for Small and Medium Powers," Institute of Defence and Strategic Studies, Singapore, May 2004. <http://www.idss.edu.sg/publications/WorkingPapers/WP66.PDF>

[15] "UAV Datasource – Lark," *Shepard UVOnline*, n.d. <http://www.shephard.co.uk/UVonline/UVSearch.aspx?Action=-1427839629&ID=89f941bd-c6a0-4ae0-9b2b-5e817d8aa73c>

[16] "Denel Aerospace UAVs," Denel Web site, n.d. <http://www.denel.co.za/Aerospace/UAV.asp>, and Peter LaFranchi, "Denel Develops Mini-UAV for Medical Courier Ops," *Flight International*, June 9, 2006.

Europe

European UAV development ranks third in the world behind the United States and Israel. In Europe, France, Germany, Italy, the Netherlands, and Norway all produce mini or micro UAVs. European manufacturers have experience in all facets of UAV production and research including airframe, avionics, communications, and sensor technologies. In addition, researchers in several European nations are working on flapping-wing UAVs, including at the United Kingdom's Cranfield University, the University of Paris, and Delft University in the Netherlands.[18] Moreover, in 2005 Finnish company Robonic, a UAV launcher and component manufacturer, built a UAV test center in a remote part of the country that offers year-round flight operations and a basic airfield infrastructure where customers can develop and test UAV systems and train operators to control them.[19]

Asia

In Asia, research on UAVs is being carried out in China, India, Japan, Singapore, and South Korea. South Korean researchers excel in flapping-wing, small tilt-rotor, VTOL, and swarming UAVs while Singapore is also working on VTOL UAVs. Japan is a big user of UAVs in agriculture and in the development of small, helicopter-like VTOL UAVs. The Indian navy has been known to use large UAVs in search and rescue missions, including after the December 2004 tsunami.[20]

China has worked on military UAVs since 1965.[21] Although Chinese UAV programs began by using U.S. and Russian designs, today China is producing original research and its own

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<http://www.flightglobal.com/Articles/2006/09/25/Navigation/326/209218/Denel+develops+mini-UAV+for+medical+courier+ops.html>

[17] Peter LaFranchi, "South Africa's UAV Duo ATE and Denel in Merger Talks," *Flight Global*, September 25, 2006. <http://www.flightglobal.com/Articles/2006/09/25/Navigation/326/209215/South+Africa's+UAV+duo+ATE+and+Denel+in+merger+talks.html>

[18] "Delft University to Expand DelFly MAV Capability," *Janes' International Defence Review*, April 1, 2006. <http://www.janes.com/>

[19] "Robonic to Launch UAV Test Flight Centre in Finland." UVS Canada, September 12, 2005. <http://uvscanada.org/blog/?p=43>

[20] "Israel Sells Heron UAVs to India, Australia," *Defense Industry Daily*, November 11, 2005. <http://www.defenseindustrydaily.com/2005/11/israel-sells-heron-uavs-to-india-australia/index.php>

[21] "Unmanned Aerial Vehicles (UAVs)," *Global Security* <www.globalsecurity.org/military/world/china/uav.html> (Accessed 10/24/2006).

designs. China is designing and building mini, micro, VTOL, and flapping-wing UAVs. Among the many Chinese universities and research institutions involved in UAV research are the Beijing Technology Company, Beijing University of Aeronautics and Astronautics, China Aerospace Science and Technology Corporation (CASC), Hebei Electric Power Reconnaissance Design Academy, Northwestern Polytechnical University, Shaanxi Engine Design Institute, and Xian ASN Technology Group Company.[22]

Russia and Ukraine

Russia has a long history of UAV development and research. Russia started using target drone UAVs in the 1950s, and by the 1980s the Pchela–1 UAV, with a 2.7-meter wingspan, was developed to carry cameras and electronic warfare payloads. In the 1990s, Russian scientists began early swarming research, linking up to 10 large UAVs in flight for combat operations. The system was used in Chechnya but with questionable results, and lack of funding for the research stopped operations. Russia's leading UAV manufacturer, Irkut, has six UAV models. Two of these models, the Irkut 2 and the Irkut 20, have wingspans of less than two meters in length. Irkut is currently working on flying four Israeli-built, 6.5-meter wingspan Aeronautics Aerostars at the same time for reconnaissance.

Some experts have raised questions about the potential of the Russian UAV industry. Few of the Russian UAV designs have "a solid engineering basis," according to a May 2006 report in *Jane's Defence Weekly*.[23] The report notes that Russian UAV manufacturers have some experience in UAV development but have failed to produce modern designs. Other analysts believe the Russian UAV industry has the potential to be a world leader but has suffered from lack of funding.[24] The Russian Federation Armed Forces, for example, have not used UAVs to the same extent as the United States and other advanced technology countries. Major General Igor Sheremet, chief of the Information Analysis Directorate of the Federal Service for the Defense Order, has identified a number of areas where Russia needs to catch up to the United States and other developed nations, including in UAV development and production. Sheremet believes that Russia must improve its unmanned aviation program and has the technical

[22] David, Hewson, Kemp, and Trimble.
[23] David, et. al., 4.
[24] Oleg Vladykin, "Unmanned Aerial Breakthrough," *The Moscow News*, October 24, 2006. <http://mignews.com/ua/en/articles/213361.html>

capability to do so. According to Sheremet, Russia's priorities in the field of UAVs should be to develop a defense against enemy UAVs, to improve mini, micro, and nano UAV platforms, and to improve the theory and algorithms for swarming UAVs.[25]

Ukraine also produces UAVs. The Ukrainian National Aerospace University has produced two mini UAV surveillance systems: the day and night reconnaissance AIST and BEKAS.[26] Scientific Industry System (SIS) produces a two-meter wingspan UAV (Remez–3) which can carry video cameras and send video to UAV operators via a real-time downlink.[27] SIS also produces the 1.425-meter wingspan Albatross–4K. The Albatross–4K can carry a global positioning system, two television cameras, and a video transmitter. The SIS UAVs are designed for observation and reconnaissance.[28]

TRENDS IN MINI AND MICRO UAV DEVELOPMENT

Over the years, the size of UAVs has been reduced. The first UAVs used for antiaircraft practice in the 1930s were full-sized airplanes. Today, micro aerial vehicles are the smallest UAVs in operation. This report focuses on mini and micro UAVs as well as VTOL, flapping-wing, and swarming UAVs. Although no internationally agreed upon classification system exists for UAVs, this report considers UAVs with wingspans shorter than two meters in length to be mini and those with a wingspan shorter than 30 centimeters to be micro. Researchers in Germany, Israel, Italy, the Netherlands, South Korea, and the United Kingdom are designing and building mini UAVs to perform missions heretofore carried out by larger craft. The smallest known deployed flying micro UAV in the world is AeroVironment's (United States) Black Widow, which has a 23-centimeter wingspan and weighs 56 grams. Although state-of-the-art VTOLs have not yet been miniaturized to a size much smaller than two meters in rotor diameter,

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[25] Igor Sheremet, "Network Centric Warfare: Origins and Technical Aspects," *Voyenno-Promyshlennyy Kuryer* [Moscow], February 22, 2006 (via Open Source Center CEP20060221436014). <https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_1019_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/5950102?action=advancedSearch&highlightQuery=eJzTcHYNMDIwMDMwMjI0MTYzMDTRBAAougPp&fileSize=100614>)

[26] "AIST Unmanned Aerial Surveillance System," Kharkiv Aviation Institute Web site <http://www.khai.edu/niipfm/english/aist-en.htm> (accessed 10/24/2006); and "Bekas Unmanned Aerial Surveillance System," Kharkiv Aviation Institute Web site <http://www.khai.edu/niipfm/english/bekas-en.htm> (accessed 10/24/2006)

[27] "Scientific Industrial Systems, Ltd," Construction Bureau Assent <http://vzlet.com.ua/index_english.html> (accessed 11/9/2006).

[28] Scientific Industrial Systems, Ltd."

current flapping-wing UAVs range in size from 15 centimeters to around 36 centimeters. For the purposes of this report, the term swarming when applied to UAVs is defined as a collection of individual UAVs that moves and changes direction as a group, such as is seen in the animal world when birds, insects, or fish create groups of their own kind for safety or to hunt for food.

Miniature UAVs

Any UAV with a wingspan less than two meters but greater than 30 centimeters is considered a mini UAV (MUAV). MUAVs are suitable for ISR, battlefield evaluation, NBR detection, communications relay, wiretapping, radar interference, and operations in cities and high-density population areas.

What many MUAVs lack, however, is a viable guidance navigation system (GNS) and power system that can fit within their confines. Zhang Xiao and Fang Jiancheng of the Beijing University of Aeronautics and Astronautics have designed a GNS small enough to work in a MUAV. It is 70 by 100 by 70 millimeters, weighs 300 grams, requires only 4 watts of power, and is able to withstand strong vibration while delivering fairly precise altitude and position information. Zhang and Fang installed their GNS in a UAV with a 1.4-meter wingspan and proved the system was capable of providing accurate information to 1 degree in attitude and positions within 10 meters of actual location.[29]

Micro Aerial Vehicles

A micro aerial vehicle (MAV) is any UAV that has a wingspan of 30 centimeters or smaller. MAVs are useful for battlefield reconnaissance, air monitoring, NBR detection, target identification, and communications relay. MAVs also can be used to reconnoiter building interiors. Research institutes worldwide are developing MAV technology, including, for example, the Beijing Aerodynamics Research Institute of Astronautics, which is developing a prototype with a wingspan of between 220 and 600 millimeters and a maximum takeoff weight of 0.12 to 1.5 kilograms.[30] It is capable of flying more than 100 kilometers per hour and cruising

[29] Zhang Xiao and Fang Jiancheng, "A Design of Low Power, High Capability GNC System of Micro Unmanned Aerial Vehicle," AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005, San Francisco (AIAA 2005–6285).
[30] Li Shouan, Zhang Hengxi, Guo Feng, and Li Dengke, "Actuality, Development Trend of Micro Air Vehicles," *Beijing Daodan Yu Hangtian Yunzai Jishu*, June 1, 2005 (via Open Source Center CPP20060518324002).

at between 10 and 36 kilometers per hour at an altitude of 100 to 300 meters for 10 to 30 minutes. French researchers also are working on micros. The French Mirador concept MAV is 25 centimeters long and uses miniature fuel cells to drive a propeller. It is being developed by the French National Aerospace Research Center, French Ministry of Defense, and Royal Military Academy of Belgium.[31] Additionally, AeroVironment (United States) has developed the smallest MAV, the Black Widow, and BAE Systems, USA also has built MAVs.

A primary difficulty in engineering MAVs involves propulsion. It is difficult to make internal combustion engines both small enough to fit in MAVs and efficient enough to produce enough energy to create thrust. Fuel cells, micro-turbo generators, and thermo-photoelectric engines might prove a better power source than internal combustion engines for the MAV. Most companies turn to electric motors because many small electric motors are available commercially; they are also quieter than gasoline-powered engines. A problem for electric propulsion, however, is storing the energy to power the motors. New battery technology, such as lithium polymer cells, may allow MAVs and MUAVs to stay in the air longer than they could using current battery technology.[32] Other innovations that might help solve this MAV propulsion problem are under development. NASA, for example, has created an experimental 1.5-meter wingspan mini UAV that is powered by laser beams directed at the craft from the ground.[33] Americans also are working on solar-powered UAVs. In June 2005, the 4.74-meter wingspan SoLong UAV, made by AC Propulsion, a California company, flew for 48 hours straight, using the sun to recharge its batteries during the daylight hours.[34] Researchers at Turin Polytechnic University in Italy are designing a larger, high-altitude, solar-powered UAV as well, the

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[31] Yves Ribaud and Olivier Dessornes, "Micropropulsion Microcombustion," Aerospace Research and Technology, September 24, 2002. <http://www.onera.fr/conferences/micropropulsion/>

[32] Plantcro Hobbies, "Lightweight Batteries With Superior Energy Density." <http://www.plantraco.com/hobbies/product-lpcells.html>

[33] United States, National Aeronautic and Space Administration, "From Gas-Powered to Laser-Powered! NASA Research Team Successfully Flies First Laser-Powered Aircraft," October 9, 2003. <http://www.nasa.gov/centers/marshall/news/news/releases/2003/03-180.html>

[34] "AC Propulsion SoLong UAV Flies for 48 Hours on Sunlight. Two Nights Aloft Opens New Era of Sustainable Flight," *AC Propulsion*, June 2, 2005. <http://www.acpropulsion.com/ACP_DOCs/ACP_SoLong_UAV_48hr_Flight_2005-06-05.doc>

HELIPLAT, which is designed to climb to an altitude between 17 and 20 kilometers.[35] Although these new technologies have not yet been miniaturized to fit into mini or micro UAVs, they represent a possibility for new innovations in UAV propulsion technology.

Flapping-Wing UAVs

A flapping-wing UAV is a type of MAV that uses wing motion instead of propellers to move. The U.S. Defense Advanced Research Projects Agency (DARPA) and Rand Corporation first proposed flapping-wing MAVs in 1992 for intelligence, surveillance, and reconnaissance missions.[36] France, the Netherlands, the United Kingdom, and the United States are leaders in the flapping-wing UAV field; China, Israel, and South Korea also are working on developing flapping-wing UAVs.

Researchers at Delft University in the Netherlands are developing the DelFly flapping-wing MAV, the wings of which have been designed to imitate the flapping action of insect and bird wings.[37] The DelFly weighs only 17 grams, has a mini onboard camera for reconnaissance, and is able to fly forward or to hover. The DelFly has been designed for swarming, for facial recognition of persons within crowds, and for urban scouting.

Researchers on the French ROBUR flapping-wing UAV project are working on creating an autonomous, flapping-wing UAV that has the capacity for object avoidance, switching between hovering and forward flight, and adapting to changes in atmospheric conditions, such as wind gusts and wind direction.[38]

[35] Giulio Romero and Giacomo Frulla, "HELIPLAT: Aerodynamic and Structural Analysis of HAVE Solar Powered Platform," AIAA's First Technical Conference and Workshop on Unmanned Aerospace Vehicles, May 20–23, 2002, Portsmouth, Virginia (AIAA 2002–3504).

[36] Li Shouan, Zhang Hengxi, Guo Feng, and Li Dengke, "Actuality, Development Trend of Micro Air Vehicles," *Beijing Daodan Yu Hangtian Yunzai Jishu*, June 1, 2005 (via Open Source Center CPP20060518324002). <https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_1019_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/6155168?metadataDisplay=false&historyDisplay=true&printerFriendly=true>

[37] "Delft University to Expand DelFly MAV Capability," *Janes' International Defence Review*, April 1, 2006. <http://www.janes.com/>

[38] Jean Baptiste Mouret, Stephane Doncieux, and Jean-Arcady Meyer, "Incremantal Evolution of Target-Following Neural Controllers for Flapping Wing Animats," Animat Lab, Paris University, 2006. <http://people.happycoders.org/mandor/slides_sab.pdf>

Tilt-Rotor and Vertical-Takeoff-and-Landing UAVs

Two other innovations in UAV design are tilt-rotor and vertical-takeoff-and-landing UAVs. Tilt-rotor aircraft feature the ability to hover like a helicopter, enabling a vehicle to loiter directly over a target and to fly at high speeds. Although the U.S. company Bell Helicopter is working on a tilt-rotor UAV, most of the research on small tilt-rotor UAVs is being done in South Korea. For example, researchers at the Korea Aerospace Research Institute (KARI) have been working on tilt-rotor UAVs since 2002. In 2004 KARI researchers tested tilt-rotor UAV designs in wind tunnels to determine maximum efficiency.[39] In 2005 other KARI researchers reported on their use of computational fluid dynamics to study rotor performance and rotor wake of tilt-rotor aircraft to find better stability and air speed.[40]

VTOL UAVs are also gaining popularity, mainly because of their ability to quietly linger in one spot for an extended period of time. Some are being equipped with microphones in order to listen to conversations. VTOLs can look like small helicopters, a design that is popular in Japan, or ducted fans, a design popular elsewhere around the world. Companies in the United States have built many kinds of VTOL UAVs, but France, Israel, Italy, Singapore, South Korea, and the United Kingdom also have designed and built VTOLs. For example, Singapore Technologies Aero has developed a ducted FanTail VTOL.[41] This design, which has a rotor diameter of 0.29 meters and a length of 0.76 meters, has a video camera and flies under autonomous control. It can carry microphones, munitions, and chemical sensors. Development began in 2001 and was completed in 2004.

[39] Cheol Wan Kim, Sang Oh Chu, Pyonghee Chang, and Jin Duk Chung, "The Research on Aerodynamic Database for Real Time Flight Simulation of the Tilt-Rotor UAV," KARI, 2004. KARI–ADG–RP–2004–028. <http://aero.kari.re.kr/korean/paper/RP/ADG-RP-2004-028.PDF>

[40] C.W. Kim, Y.M. Park, B.H. Chang, and J.Y. Lee, "Analysis of Tilt-Rotor Aircraft with Power Effect," The 6th Asian Computational Fluid Dynamics Conference, October 24–27, 2005, Taipei, Taiwan. <http://aero.kari.re.kr/Korean/Paper/RP/ADG-RP-2005-022.pdf>

[41] "ST Aero FanTail," *Jane's Unmanned Aerial Vehicles and Targets*, May 21, 2004. <http://www4.janes.com/subscribe/juav/doc_view.jsp?K2DocKey=/content1/janesdata/binder/juav/juav9492.htm@current&Prod_Name=JUAV&QueryText=%3CAND%3E%28%3COR%3E%28%28%5B80%5Dvtol+%3CIN%3E+body%29%2C+%28%5B100%5D+%28%5B100%5Dvtol+%3CIN%3E+title%29+%3CAND%3E+%28%5B100%5Dvtol+%3CIN%3E+body%29%29%29%29>

SWARMING UAVs

A swarm has been defined as "modeled flight that is biologically inspired by the flights of flocking birds and swarming insects."[42] Although many swarming studies of nonaerial vehicles, such as small cars and small robots, have been made since the 1970s, studies of grouping UAVs did not begin until the early 1990s. Researchers believe a swarm of UAVs can perform like a network of assets and complete missions that have been reserved for larger UAVs or manned aircraft. Working as a network, a swarm of UAVs can combine the capabilities of individual UAVs to provide timely battlefield information and/or act together to perform long, dull, and dangerous military missions. Moreover, by using multiple mini or micro UAVs rather than a single large one, many missions can be performed with greater efficiency. In addition, a swarm of inexpensive mini and micro UAVs possesses a redundancy advantage, that is, if one member of the swarm is lost in action, the rest of the swarm can carry out the mission.

Although many envision swarms of mini or micro UAVs, larger UAVs can also be used in swarms. In fact, UAVs of different sizes, such as a combination of mini and micro UAVs, can be used in a swarm for a single operation. Although researchers from Australia, Germany, Israel, the Netherlands, the United Kingdom, and the United States are at the forefront of swarming research, other countries, such as South Korea and China, also are conducting research in swarming. These countries have studied and designed theories and technologies that enable UAVs to fly together to a target, undertake a mission, and return to base.

A swarm of UAV vehicles has two main obstacles to overcome during flight. The first challenge is keeping the UAVs from crashing into one another (collision avoidance); the second is keeping the swarm on its mission, whether it may be to search an area or to travel to a specific target.

Collision Avoidance

In order to have a successful swarming operation, an individual UAV must be able to fly in proximity to its mates yet avoid colliding with them. Researchers in the United States and the United Kingdom have looked at collision avoidance since the early 1990s; South Korean and Chinese researchers have looked into this issue since the end of the 1990s.

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[42] "Atair Aerospace Becomes First to Demonstrate Flocking and Swarming Capabilities," Atair Aerospace, Press Release, March 3, 2005. <http://www.atairaerospace.com/press/2005/03/atair-aerospace-becomes-first-to.html>

One experiment for coordinating individual UAV movement within a swarm was offered in 2003 by South Korean researchers from the Korea Advanced Institute of Science and Technology (KAIST).[43] In this study, researchers considered a swarm to be a decentralized group where each individual, without seeing the entire swarm, performs simple maneuvers to avoid colliding with other members of the swarm. This concept is similar to that of an individual driving on a crowded highway. Although the individual cannot see all the traffic at once, he is able to maintain proper distance from other cars on the highway in order to avoid accidents. By combining collision avoidance, velocity matching (flying at the same speed as other UAVs in the swarm), and flock-joining (the act of flying beside and around other UAVs) behaviors, the KAIST researchers simulated complex behaviors found in schools of fish and flocks of birds and applied them to UAV operations. The researchers found that a safety bubble of five to 15 times the body length of the UAV allows a UAV to avoid collision with other UAVs in a swarm. If one UAV enters the safety zone of another, they both will maneuver to maintain their safety bubbles. In addition, the KAIST researchers developed a program that allowed a UAV to maintain a specific distance from its two closest swarm neighbors and fly slowly enough to not run into the vehicle ahead, yet fast enough to avoid being run into by the one behind.

Researchers at the University of Padua, Italy, studied the use of cameras mounted in UAVs to enable them to avoid collisions within a swarm.[44] The researchers studied computer graphics of a flock of birds and found that the birds followed simple rules that allowed them to stay close to the flock but also avoid collisions, much as the South Korean researchers found in their study. Based on the theory that birds use their vision to stay with the flock, the Padua researchers created a geometric model for a vision system that allowed camera systems on board UAVs to help the vehicles maintain position within a flock. The researchers found that the greater the camera view angle and view distance capability, the greater the flocking capability. Similar to the work done at KAIST, the Padua study, performed between 2003 and 2004, showed that individual UAVs employed collision avoidance, velocity matching, flock centering (trying

[43] Chang-Su Park, Min-Jea Tahk, and Hyochoong Bang, "Multiple Aerial Vehicle Formation Using Swarm Intelligence," AIAA Guidance, Navigation, and Control Conference and Exhibit, August 11–14, 2003, Austin, Texas (AIAA 2003–5729).

[44] Guido Maria Cortelazzo, Adrian F. Clark, and John C. Woods, "Flocking of UAVs Software Model and Limited Vision Simulations," University of Padova, Academic Year 2003–2004. <http://privatewww.essex.ac.uk/~rdenar/De_Nardi_Renzo2005thesis.pdf#search=%22Flocking%20of%20UAVs%20Software%20Model%20and%20Limited%20Vision%20Simulations%22>

to stay close to the center of the swarm), and a sensor space (similar to KAIST's safety bubble) to avoid colliding.

In 2004 another group of researchers at KAIST proposed proportional navigation (PN) to help keep UAVs from colliding with one another in a swarm.[45] The researchers investigated PN guidance law, which has been successfully used in missile guidance, in order to find a collision-avoidance algorithm applicable to UAVs. To apply PN guidance law to collision avoidance, the researchers defined a sufficient condition for collision avoidance and, using mathematical equations, defined a collision-voidance vector. In this experiment, researchers found that, upon encountering an obstacle, the UAV used an equation to plot acceleration, relative velocity, and the direction of a collision-avoidance vector. When the UAV triggered its collision-avoidance mode, it performed a maneuver to avoid collision, switched off the collision-avoidance system, and turned on the navigation mode. Upon review of test results, the researchers concluded that the PN collision-avoidance law used in missile guidance can be applied successfully to UAVs.

Path Planning

Once individual UAVs can form and fly as a flock without colliding in mid-air, the swarm is ready to perform its mission to search an area or arrive at a target location. Planners must select paths either for searching areas or for travel to target locations and also take into consideration such things as fuel capacity and distance when choosing the optimal path. Although the United States and Israel have led the world in path-planning research, China and the Netherlands also have conducted studies in the field. Chinese researchers have studied ant food-finding algorithms to address path planning. Dutch researchers have applied path-planning techniques particularly for unmanned combat aerial vehicle (UCAV) missions, in which the UCAVs not only seek and find the enemy but also attack him with weapons.[46] These studies are discussed below.

[45] Su-Cheol Han and Hyochoong Bang, "Proportional Navigation-Based Optimal Collision Avoidance for UAVs," 2d International Conference on Autonomous Robots and Agents, December 13–15, 2004, Palmerston North, New Zealand.
<http://www.ist.massey.ac.nz/conferences/icara2004/files/Papers/Paper13_ICARA2004_076_081.pdf#search=%22Proportional%20Navigation-Based%20Optimal%20Collision%20Avoidance%20for%20UAVs%22>

[46] B.R.R. Vandermeersch, Q.P. Chu, and J.A. Mulder, "Design and Implementation of a Mission Planner for Multiple UCAVs in a SEAD Mission," AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005, San Francisco (AIAA 2005–6480).

In 2005 researchers from the Shaanxi Engine Design Institute in Xian, the Hebei Electric Power Reconnaissance Design Academy, and the Aircraft Engineering Department of Northwestern Polytechnical University studied ant colony coordination characteristics to develop algorithms for leading UAVs on optimal paths to targets.[47] The researchers applied a probability equation to track the routes of the first and subsequent ants to their target and back to the colony. The researchers then viewed the network of routes taken by the ants to obtain food in terms of a least-distance tree, a visual chart of the least amount of distance an ant takes to find food. By using graph theory, an algorithm can compute a least-distance tree to find optimal routes for UAVs. The researchers concluded that ant algorithms can be used to plot UAV mission paths that feature acceptable path lengths and small detection probability. Using the point at which a UAV enters an enemy area as one azimuth and the target as another azimuth, the researchers tried to establish a network graph that provided an optimal path to the target.

The challenge for a mission planner is to find a threat-free path through enemy territory to the target. Because the most obvious and shortest routes to targets often have the best defense, finding the safest way and spending the least amount of time in the air are critical tasks.[48] In 2005 researchers at Delft University in the Netherlands pursued optimal path planning in a swarm using basic mathematical formulas, rules, and approximation (a heuristic method) to design routing for a simulated, autonomous swarming mission of large UCAVs to suppress enemy air-defense missions.[49]

Delft researchers constructed an algorithm that reflected the importance of distance, time, and effort required for UCAVs to knock out enemy sites. Using the formula, the researchers searched for the optimal trajectory through the target area using visibility graphs.[50] A network flow program was used to aid in the task of UCAV assignment, in which UCAVs were weighted based on the number of munitions they carried, and enemy sites were weighted by their capabilities. For example, more UCAVs were assigned to missile sites with greater capabilities while fewer UCAVs were assigned to loiter in a safe area or to look for offline missile sites. The

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[47] Liu Chang'an, Liang Guangping, Wang Heping, and Li Wieiji, "Application of Ant Algorithm to Path Planning to Reconnaissance UAV," October 1, 2005 (via Open Source Center ID: CPP20060308424002). <https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_1019_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/5975352?action=advancedSearch&highlightQuery=eJzTcA4IMDIwMDMwNrAwMTIxMDDSBAApjgP0&fileSize=387686>
[48] Vandermeersch et al, 2.
[49] Vandermeersch et al, 2.
[50] Vandermeersch et al, 4.

researchers then developed a network of UCAVs and targets and calculated the cost of the distance between each UCAV and its target. The researchers concluded that their approach worked well and that a mixture of techniques, such as task assignment, network flow programming, visibility graphs, and algorithms enhanced the effectiveness of the mission. The uniqueness of this approach lies in its ability to adapt to changes in mission plans.[51] Although the simulation was based on larger UAVs, it is envisioned that mini and micro UAVs could carry out similar attack missions in the future.

Swarm Search Patterns

In order to conserve fuel and minimize the amount of time a UAV is in enemy territory, UAV search patterns must cover territory efficiently, that is, cover as much territory as possible in the least amount of time. Finding enemy targets sooner helps promote deterrence and improves war-fighting capabilities. Swarm search patterns have been the focus of research at Technion in Israel and the Institute of Science in Bangalore, India.

In 2004 researchers at Technion, the Israel Institute of Technology in Haifa, considered mission execution performance based on flock properties in an effort to develop a heuristic algorithm that was capable of incorporating target and group property changes without the computational complexity that such missions normally require. [52] They contended that many studies focused on optimal algorithms that may have provided better task results but were so computationally complex that they did not react well to changes in system properties, such as changes in swarm capabilities or the loss of individual UAVs. That is, some algorithms took so much time to develop and compute that the cost of each mission escalated, making mission cost prohibitive. The Technion study focused on the number of UAVs (system size), the maximum distance UAVs can fly from one another and still communicate (communication range), and the amount of data UAVs can share with one another (communication bandwidth).[53]

The Technion researchers ran a study of autonomous UAVs communicating with one another to perform a search, identify, and destroy mission against moving enemy ground

[51] Vandermeersch et al, 8.
[52] Elad Kivelevitch and Pini Gurfil, “Taxonomy of Mission Performance for Diverse and Homogenous UAV Flocks,” AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005, San Francisco (AIAA 2005–5828).
[53] Kivelevitch and Gurfil, 1.

vehicles. The experiment found that using more UAVs was more effective than using fewer vehicles because it was easier to perform multiple missions at the same time. The experiments also showed that communication among UAVs allowed for more precise task management and improved mission efficiency by allowing the flock to disperse and cover a larger area; limiting communication range led to poor performance for all sizes of swarms.

In another experiment in 2005, researchers at the Indian Institute of Science in Bangalore studied time constraints in optimal search route decisions.[54] In their study, they proposed "a game theoretical approach to route decision-making that takes into account various levels of communication capabilities possessed by UAVs while taking the flight time (or refueling) constraint into account."[55] They used a shortest-path algorithm for route planning but used game theory to account for changes in uncertainty and the existence of other UAVs. The researchers created an algorithm that considered the number of bases, base cells, duration, and return to base and then created and plotted a virtual uncertainty map in order to determine the optimal search route.[56] A successful search visits areas that have large uncertainty values. As the UAV flies through clusters of cells and collects information, the uncertainty level of an area is reduced. The game theory employed in the study took into account the limited information the UAV may possess during a mission and tried to determine how effective a search could be in different scenarios. The researchers used one calculation to determine the search effectiveness when UAVs are in communication and another calculation to determine search effectiveness when they are not and found that the non-cooperative strategy (without communication) performed almost as well as the cooperative strategy (with communication).[57]

Also in 2005, researchers from Technion in Israel presented two algorithms for programming UAVs to search areas for targets.[58] These algorithms produced flying patterns "designed for scanning a rectangular area in such a way that the targets cannot reenter subareas which were already scanned."[59] The first algorithm purported better searching through better

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[54] P.B. Sujit and Debasish Ghose, "Search by UAVs with Flight Time Constraints Using Game Theoretical Models," AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005, San Francisco (AIAA 2005–6241), 1.
[55] Sujit and Ghose, 1.
[56] Sujit and Ghose, 3.
[57] Sujit and Ghose, 9.
[58] Yaniv Altshuler, Vladimir Yanovsky, Israel A. Wagner, and Alfred M. Bruckstein, "The Cooperative Hunters—Efficient Cooperative Search for Smart Targets Using UAV Swarms," Technion University. <http://www.cs.technion.ac.il/people/yanival/online-publications/UAVs.pdf>
[59] Altshuler et al, 1.

flying patterns than those produced by other research efforts, and the second algorithm was fault-tolerant, allowing UAVs to search areas of unknown size and shape. The research found that this approach requires a high level of communication among individual UAVs.

Ultraswarm

An ultraswarm is a group of UAVs that not only behave like a swarm but can combine their computing power to form a network that can analyze task-related computations. [60] Thus, a swarm of UAVs could perform some of the functions of AWACs, such as data analysis. Researchers at the University of Essex, United Kingdom, are currently working on UAV ultraswarm theory using a miniature helicopter weighing 50 grams equipped with a computer, video camera, and Bluetooth link. The helicopter was able to act as a Web server for its own project and transmitted its camera’s images to a Web site, thus demonstrating the possibilities of transmitting streaming data and forming a wireless network of small UAVs. This research is ongoing.[61]

UAV Vulnerability

Large UAVs are susceptible to detection and destruction. Although there are no known incidents where mini and micro UAVs have been shot down, some examples of successful actions against larger UAVs over the past seven years are listed below.

- In Apri1 1999, a U.S. Hunter UAV was shot down by Yugoslav air defense forces over Pristina, Kosovo, and a U.S. Predator was shot down over Biba, Serbia, by a surface-to-air missile.[62]
- In August and October 2001, U.S. Predators were shot down over Iraq by antiaircraft fire,[63] and in December 2002 a U.S. Predator was shot down by a missile from an Iraqi fighter plane.[64]

[60] Owen Holland, John Woods, Renzo De Nardi, and Adrian Clark, “Beyond Swarm Intelligence: The Ultraswarm,” IEEE Swarm Intelligence Symposium SIS2005, June 8–10, 2005, Pasadena, California. <http://cswww.essex.ac.uk/staff/owen/SIS2005copyright.pdf#search=%22%22beyond%20swarm%20intelligence%3A%20the%20ultraswarm%22%22>
[61] “The Ultraswarm,” Essex University. Modified July 31, 2006. <http://gridswarms.essex.ac.uk/technologies.html>
[62] “Officially Confirmed/ Documented NATO UAV Loses,” January 6, 2001. <http://www.aeronautics.ru/official/lostuavs.htm>

- In July 2006, an Israeli-built B–Hunter UAV was reportedly shot down by a single rifle bullet shot by a lone rebel gunman. The shot broke a wing spar on the UAV while it was preparing to land at an airport in Kinshasa, Democratic Republic of Congo. The almost 9-meter long IAI B–Hunter was being flown by the Belgian military to observe automobile traffic and crowds as part of the European peacekeeping force EUFOR Congo in support of the local government.[65]
- In August 2006, a Hezbollah UAV was shot down by the Israeli Air Force. No details on the means used to bring down the UAV have been divulged.[66]

Nonetheless, larger UAVs have had success against modern defense systems. On November 7, 2004, for example, a flight by a large Hezbollah UAV traveled about 14 kilometers before it crashed on its own into the Mediterranean Sea off Lebanon.[67] Just five months later, on April 11, 2005, Hezbollah militants flew another large UAV into Israel. The flight lasted nine minutes and covered 29 kilometers over Israeli territory. It has been reported that Israel had prior knowledge of the UAV flight and scrambled fighter aircraft and attack helicopters but still could not find or destroy the UAV. In response to the April 2005 incident, retired Israeli Major General Eitan Ben-Eliah said that the Israeli air defense system was built to locate fighter aircraft, attack helicopters, and missiles but would need to be modified to locate and track small, slow targets such as mini and micro UAVs.[68] Mini and micro UAVs are very difficult to find, identify, and shoot down because they have a very small radar cross section and travel at low altitudes and low speeds. To date, there have been no reports of any mini or micro UAVs having been shot down.

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[63] Kathleen T. Rhem. “Iraqi Plane Shoots Down American Predator Unmanned Aircraft,” *Armed Forces Information Service*, December 23, 2002. <http://www.defenselink.mil/news/Dec2002/n12232002_200212236.html>
[64] Rhem.
[65] “Belgium Resumes Congo UAV Operations After B-Hunter is Shot Down,” *Flight International*, August 14, 2006.
<http://www.flightglobal.com/Articles/2006/08/14/Navigation/177/208465/Belgium+resumes+Congo+UAV+operations+after+Hunter-B+is+shot.html>
[66] “Israel Media Assess Hizballah Use of UAVs in Lebanon Conflict,” August 8, 2006 (via Open Source Center FEA20060809026111).
<https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_51_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/6287596?action=advancedSearch&highlightQuery=eJzTcHN1NDIwMDOwMLA0MDIzNDTUBAAoRgPi&fileSize=8322>
[67] Barbara Opall-Rome, “UAV Finds Flaw in Israeli Air Defenses,” *C4ISR*, April 18, 2005.
<http://www.isrjournal.com/story.php?F=792603>
[68] Opall-Rome.

UAV APPLICATIONS

Large and small UAVs can be used in a wide variety of military and commercial applications. Their range of military uses includes ISR, NBR detection, communication relay, and search and rescue. Outside the military arena, utility companies and government inspectors use low-cost UAVs to monitor and inspect electricity and communications wiring in limited-access areas, where UAV-mounted cameras and sensors can be used to detect downed lines, cut cables, damaged towers, worn poles, and overgrown vegetation. UAVs also can be used to monitor agricultural conditions, algae blooms, animal and human migration, automobile traffic, borders, floods, forests, ice, pipelines, pollution, ports, snow packs, soil moisture, solar radiation, weather, wetlands, and wild fires.

Agriculture

Pest control and the monitoring of plant health and growth are two agricultural uses for UAVs. In 2004 in Japan, for example, the number of hectares sprayed for pest control by UAV helicopters surpassed the number of hectares sprayed by manned helicopters.[69] Yamaha Motor Company (Japan) has had great success with its RMAX Type II G helicopter in pest-control spraying. The RMAX employs an onboard GPS system to detect position and uses the Yamaha Attitude Control System to control flight through the manipulation of direction, elevation, and speed. The Yamaha RMAX can also be equipped with sensors that can collect data for leaf color maps that indicate plant growth, pest infestation, and blight. Although the RMAX UAV is not considered a mini or micro UAV, there is potential for miniaturization of this mature platform.[70]

Researchers have loaded multispectral sensors into a UAV and flown it in precise patterns over crops. Images and data are sent in-flight from the UAV and downloaded to laptop computers for real-time mapping. Through this means, other crops, both legal and illegal, can be monitored for ripeness, blight, pest infestation, and drought. For example, researchers at Clark

[69] "Agricultural Applications," Yamaha Motor Company. <http://www.yamaha-motor.co.jp/global/industrial/sky/agricultural/index.html>
[70] "Plant Growth Survey/Rice Paddy Remote Sensing," Yamaha Motor Company. <http://www.yamaha-motor.co.jp/global/industrial/sky/solution/plant/index.html>

University in the United States have used sensors on a large, solar-powered UAV to monitor coffee bean ripeness in Hawaii.[71]

Disaster Assistance

UAVs can aid in the study of natural disasters and in search and rescue efforts associated with them. In December 2004, the Indian navy flew large UAVs over Andaman and Nicobar Islands to search for tsunami survivors.[72] Large and mini UAVs were also flown over Mississippi and Louisiana after Hurricane Katrina in 2005 to assess damage and aid in rescue.[73] UAVs can also deliver supplies after disasters. Arizona's Strata Technologies, for example, claims that it can provide "miniaturized guided parafoil sensor delivery systems" that can deliver one to 181 kilograms of medicine or other supplies dropped by a UAV.[74]

Electronic Warfare

To date, the use of UAVs in electronic warfare (EW) has been focused on larger UAVs, although miniaturized radio-frequency components and small-form processor boards have the potential to drive the development of EW payloads for small UAVs.[75] Sweden's Saab Technologies has worked with Australia's Defence Science and Technology Organisation to develop EW payloads for UAVs. The Australian-built Aerosonde Mark III, a UAV with a 2.9-meter wingspan, has participated in EW experiments transmitting "real-time emitter bearings and pulse analysis data to the ground station."[76] Saab believes its work on larger UAV EW platforms will help it develop similar payloads for mini and micro UAVs. For the future, Saab is considering a modular payload system, a more powerful payload computer, and multi-UAV operations. In addition, Saab is working on an interface between the Aerosonde and Saab's

[71] "Coffee Crop Maximized by Space Technology," *ABC News* (Australia), October 23, 2002. <http://www.abc.net.au/science/news/stories/s708429.htm>

[72] "Israel Sells Heron UAVs to India, Australia," *Defense Industry Daily*, November 11, 2005. <http://www.defenseindustrydaily.com/2005/11/israel-sells-heron-uavs-to-india-australia/index.php>

[73] "USF Deploys Unmanned Aerial Vehicles to Katrina Rescue Operations," *Science Daily*, September 7, 2005. <http://www.sciencedaily.com/releases/2005/09/050908081119.htm>

[74] "Don't You Wish Your UAV Could Do This?" Strata Technologies, February 21, 2006. <http://www.medicalresupply.com/>

[75] Anthony Finn, Kim Brown, and Tony Lindsay, "Miniature UAV's & Future Electronic Warfare," Government of Australia, Defence Science and Technology Organisation (accessed October 1, 2006). <http://www.aerosonde.com/downloads/Aerosonde_DSTO_EW.pdf>

[76] David Legler, "Electronic Warfare Capabilities of Mini UAVs." <www.aerosonde.com/downloads/electronic_warfare_ledger.doc>

Network Centric Warfare Wide Area Situation Picture System, a system of communication systems that features “dominant battlespace awareness, decision superiority, and precision engagements.”[77]

Germany’s Rheinmetall Defence Electronics (RDE) also is working on EW applications for large UAVs, according to its Web site, which advertises the “airborne signal detection and signal jamming” capabilities of its UAVs.[78] According to RDE, its products provide superior information-gathering capabilities by detecting and jamming VHF/UHF radio, satellite communications systems, mobile radios, line-of-sight radios, and radar activity within a specific range. RDE also says its electronic warfare UAVs can be operated in a swarm of four units.

In addition, China’s Xian ASN Technology Group Company’s ASN–206, a large UAV with a wingspan of six meters, incorporates an EW payload that scans and jams enemy communications.[79]

Environmental Monitoring

UAVs can also help monitor and survey areas of environmental concern. Yamaha, for example, has developed an autonomous control version of the RMAX that has been used to monitor damage caused by the 2000 Mount Usu volcanic eruption in Japan. Using onboard video cameras, the RMAX recorded images of topographic changes in areas off limits to manned air vehicles and released a measurement pole into the lava to measure the thickness of the flow. Data from the UAV sensors were used to create new maps and mud and lava flow charts.[80]

Meteorology

Meteorological study is another area in which low-cost, expendable large and mini UAVs thrive, especially since UAVs can be sent up when weather conditions force manned air vehicles to stay on the ground. For example, the Aerosonde was developed by Environmental Systems and Services of Australia as a low-cost, expendable platform for meteorological study. Its

[77] “NCW Demo & Prototyping C4ISR System NetC4I,” Saab Technologies. <http://www.saabgroup.com/us/Capabilities/electronic_warfare.htm>
[78] Rheinmetall Defence Electronics. Electronic Warfare Attack/Support. <http://www.rheinmetall-detec.de/index.php?fid=2376&lang=3&pdb=1>
[79] “ASN 206 Unmanned Aerial Vehicle,” *Chinese Defence Today*, October 19, 2006. <http://www.sinodefence.com/airforce/uav/asn206.asp>
[80] “Volcanic Observation,” Yamaha Motor Company. <http://www.yamaha-motor.co.jp/global/industrial/sky/solution/volcano/index.html>

computer was designed to work with a payload of weather sensors for taking measurements. The Aerosonde vehicles have been flown over 3,500 hours on meteorological missions in Australia, Japan, North America, and Taiwan. Available since 1995, the 2.9-meter wingspan Aerosonde was the first UAV to fly across the Atlantic Ocean in August 1998.[81]

On September 16, 2005, an Aerosonde was flown by the U.S. National Oceanic and Atmospheric Administration (NOAA) into Hurricane Ophelia off the coast of North Carolina, directly above the ocean water surface, where hurricane-hunting weather reconnaissance planes do not fly. Because the temperature of the ocean is considered to be a driving force in hurricanes, the Aerosonde was deployed to gather sea temperature information by using its infrared sensor. The Aerosonde transmitted weather information that is usually provided by instruments dropped into a hurricane by manned airplanes.[82] The Aerosonde has also been used to survey polar regions and icebergs.[83]

The mini Carolo UAV, made by Germany's Mavionics, has been used by the Technical University at Braunschweig, Germany, for meteorological study of the boundary layer, a layer of air that is close to the ground and is affected by daily heat and moisture, to determine temperature, humidity, pressure, and wind vectors.[84] The Carolo models' wingspans vary from 0.4 meters to 1.4 meters; because it is highly maneuverable, the UAV can follow changes in barometric pressure and temperature. The size of the Carolo also allows it to fly precise patterns more often and at lower costs than larger, manned air vehicles. Additionally, the slow air speeds allow UAVs to collect a great amount of precise data, such as air temperature and pressure.

Network-Centric Warfare

Mini and micro UAVs also can be used in network-centric warfare (NCW) by rendering an opponent impotent by disrupting or destroying the enemy's NCW systems. Russian Major General Igor Sheremet has described how swarms of UAVs could be used to carry out attacks on NCW targets. According to Sheremet, unlike precision-guided weapons, UAVs can be used many times, can change their mission during flight, and can locate and identify targets for other

[81] Legler.
[82] National Oceanic & Atmospheric Administration, "Final Report: First-Ever Successful UAS Mission into a Tropical Storm (Ophelia - 2005)." <http://uas.noaa.gov/demonstrations/aerosonde/Ophelia_final.html>
[83] John Maurer, "Polar Remote Sensing Using an Unpiloted Aerial Vehicle (UAV)," University of Colorado, Boulder, November 20, 2002. <http://cires.colorado.edu/~maurerj/class/UAV/aerosonde.htm>
[84] Marco Bushmann, "MMAV-A Miniature Unmanned Aerial Vehicle (Mini-UAV) for Meteorological Purposes," Aerospace Systems, August 10, 2004. <http://ams.confex.com/ams/BLTAIRSE/techprogram/paper_77875.htm>

swarming UAVs.[85] Sheremet suggests that the lengthy disabling of networks is more reasonable than destruction of the same networks because destroying diverse networks would take an extreme amount of effort and resources. On the other hand, attacks that merely cause delays take less effort and fewer resources and will slow the enemy's detection-identification-target designation-engagement cycle and nullify network centrism.

Nonmilitary Use of Intelligence, Surveillance, and Reconnaissance

The police and other institutions throughout the world have begun to use UAVs for a variety of observation missions. For example,

- In 2000 Yamaha developed and mounted a gamma-ray detector onto its RMAX for use in atomic energy disasters.[86] The UAV was designed to fly into areas that are off limits because of potential contamination, take readings in the area, and transmit real-time radiation levels to a map on emergency response team laptops.
- In July 2004, Israel's IAI successfully demonstrated to police in Amsterdam how its five-kilogram, two-meter wingspan BirdEye 500 could be used to monitor traffic, train tracks, waterways, crowds, and moving vehicles. To date, the Amsterdam police have made no decision on the purchase of these UAVs.[87]
- A paper written in 2004 by researchers in the Netherlands suggests that UAVs can help monitor European gas lines in instances where flora or clouds obstruct satellite observation.[88]
- In 2004 the U.S. Department of Energy completed a successful demonstration of UAV gas pipeline observation.[89]

[85] Igor Sheremet, "Network Centric Warfare: Origins and Technical Aspects," *Voyenno-Promyshlennyy Kuryer* [Moscow], February 22, 2006 (via Open Source Center CEP20060221436014). <https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_1019_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/5950102?action=advancedSearch&highlightQuery=eJzTcHYNMDIwMDMwMjI0MTYzMDTRBAAougPp&fileSize=100614>

[86] "Volcanic Observation/Observation of Mount Usu," Yamaha Motor Company. <http://www.yamaha-motor.co.jp/global/industrial/sky/solution/volcano/index.html >

[87] "BirdEye 500 Backpackable UAV," *Defense Update*, January 28, 2005. <http://www.defense-update.com/products/s/spythere.htm>

[88] M. Van Persie, A. van der Kamp, and T. Algra, "Simulation and Optimisation of an Optical Remote Sensing System for Monitoring the European Gas Pipeline Network," National Aerospace Laboratory NLR, Netherlands. <http://www.uavm.com/images/UAV_Gas_Pipeline_Inspection.pdf>

[89] "Field Testing of Remote Sensor Gas Leak Detection Systems," U.S. Department of Energy, December 2004. <http://www.netl.doe.gov/technologies/oil-gas/publications/td/Final%20Report_RMOTC.pdf>

- In June 2006, the Los Angeles County Sheriff started using 1.98-meter wingspan Octracon (Florida) SkySeer UAVs to linger over accident and crime scenes and to search for missing children.[90]
- The Tactical Aerospace Group, based in Belize, has a Web site that claims its helicopter UAV system is the ideal way to observe and detect ruptures in oil pipelines.[91]

Terrorism

UAVs are also attractive to nonstate actors for use against their perceived enemies. Eugene Miasnikov at the Center for Arms Control, Energy, and Environmental Studies in Moscow points out that terrorists use UAVs for the same reason that the United States and its allies use UAVs: low cost, simplicity, covertness, and psychological effect.[92] As noted previously, Hezbollah, for example, has successfully used UAV platforms against Israel. "As an analysis of technical capabilities shows, UAVs can become very attractive options for terrorists anxious to deliver a covert attack with the use of chemical or biological weapons," according to Miasnikov.[93] He also notes that it would be easy for terrorists to use small UAVs to carry up to 20-kilogram payloads of chemical, biological, radiological, or conventional explosives. Moreover, writes Miasnikov, "It is very difficult to stop a terrorist UAV, once it is launched."[94] Miasnikov further points out that it is easy to convert readily available radio-controlled hobby aircraft for terrorist activity.

THE INTERNATIONAL UAV MARKET

Although the European nations, Israel, and the United States dominate open-market sales of UAVs, a growing number of Asian countries are interested in developing and selling UAVs. According to the United Kingdom's Shepard Group, a leading source of information regarding

[90] Peter Bowes, "High Hopes for Drones in LA Skies," *BBC News*, June 6, 2006. <http://news.bbc.co.uk/2/hi/americas/5051142.stm>

[91] "Pipeline Control," Tactical Aerospace Group <http://www.tacticalaerospacegroup.com/pipeline_patrol_inspection.html> (Accessed 9/29/2006).

[92] Eugene Miasnikov, "Terrorist Mini-UAVs: Technical Assessment of Capabilities," July 14, 2004. The 16th Summer Symposium on Science and World Affairs, Beijing, July 17–25, 2004. <http://www.armscontrol.ru/UAV/miasnikov-ss16_files/frame.htm>

[93] Eugene Miasnikov, "Terrorists Develop Unmanned Aerial Vehicles," The Center for Arms Control, Energy, and Environmental Studies, Moscow, December 6, 2004. <http://www.armscontrol.ru/UAV/mirsad1.htm>

[94] Miasnikov, "Terrorist Mini-UAVs: Technical Assessment of Capabilities," 27.

news and analysis of the UAV industry, worldwide expenditures on UAVs will total US$55 billion by 2016.[95] Drawing from a report by the Teal Group, a Virginia-based defense and aerospace research company, *Shepard UVOnline* says current (2006) worldwide UAV expenditures equal US$2.7 billion on an annual basis but predicts yearly expenditures will rise to US$8.3 billion in 10 years.[96] During that period, the United States will account for 77 percent of worldwide spending on UAV research, development, testing, and evaluation, followed in order by Europe, Asia-Pacific, and the Middle East. KARI claims that the Asian market will grow through 2012 and that the Asian-Pacific demand for rotary-wing UAVs will increase more than the demand for fixed-wing UAVs.[97] South America is seen as an emerging sales market.

Marketing Practices

UAV-producing companies also must adjust to market trends in order to remain commercially viable. In a 2005 paper, researchers from Israel Aircraft Industries (IAI) presented their company's approach to micro and mini UAV systems development and the international UAV market. [98] They noted that although mini and micro UAVs are useful for many tasks, the simplicity of any system among users (some with little or no UAV experience) will influence its popularity and sales. The researchers further suggested that any mini or micro system must have the capability of being launched and recovered anywhere and that it must be inexpensive so that loss of any system would be manageable. Hence, IAI strives to create mini UAVs that are small, lightweight, and easy and inexpensive to operate. To achieve these qualities, IAI chooses to consider each part and subsystem and determine whether to gradually develop its own parts or to purchase parts already available. As a result, IAI often purchases commercial-off-the-shelf (COTS) components to reduce costs and the amount of time required to integrate, test, and verify systems. For example, IAI uses commercial radio-controlled model aircraft to test components such as cameras, transmitters, GPS systems, motors, and batteries. As a result of this business decision, IAI need develop only non-COTS components.

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[95] "Teal Group Predicts Worldwide UAV Market Will Top $54 Billion, Tripling in Spending Over the Next Decade," *Shepard UVOnline*, August 31, 2006. <http://www.shepard.co.uk/UVOnline/Default.aspx?Action=-187126550&ID=e2fc1262-9e46-44d4-bec4-723e2c46d539>
[96] "Teal Group Predicts Worldwide UAV Market Will Top $54 Billion."
[97] "Aeronautics Smart UAV Development Program," Korea Aerospace Research Institute. <http://www.kari.re.kr/english/pro/pro_01_01.asp?show=21>
[98] Avi Abershitz, David Penn, Amit Levy, Aviv Shapira, and Zvi Shavit, "IAI's Micro/Mini UAV Systems-Development Approach," September 26–29, 2005, Arlington, Virginia (AIAA 2005–7034).

Illicit Sales

Illicit sales of UAVs remain a problem. Japan and Israel, in particular, have been involved in a number of cases of selling UAV technology in violation of export restrictions to China. For example, Israel's IAI Malat sold Harpy UAVs to China in 1994 and, in May 2006, was accused of selling Sparrow UAVs also to China.[99] In August 2006, Japan's Yamaha Motor Company was accused of selling the RMAX helicopter UAV to Beijing Technology Company, China, which has ties to the Chinese People's Liberation Army (PLA), in violation of Japan's Foreign Exchange and Foreign Trade Control Law.[100] Although Yamaha has claimed that the UAV cannot be used for military purposes because it is inoperable beyond radio range, the RMAX features allow it to easily be converted for long, autonomous missions. The Japanese military, for example, used the RMAX in Iraq for surveillance.[101] Another report says that Yamaha exported 11 UAV helicopters to Beijing's Poly Technologies and to Beijing Technology Company, both of which also have ties to the PLA.[102]

Marketing Testing Facilities in Europe

European airspace limitations have made it difficult for researchers to fly experimental UAVs.[103] The airspace in Europe is so crowded that other venues must be found. In response to this problem, in 2005 Finland's Robonic, a UAV launcher and component manufacturer, built a UAV test center called the Kemijarvi airfield in a remote part of the country. Robonic hopes to lure European UAV testers to their test facilities and pneumatic launchers. Unlike the crowded airspace over the rest of Europe, the Kemijarvi airfield, with its 1,200-meter runway, offers

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[99] Rebecca Anne Stoil, "Man Questioned for Illegal UAV Sales," *The Jerusalem Post*, May 22, 2006. <http://www.jpost.com/servlet/Satellite?cid=1148287839566&pagename=JPost%2FJPArticle%2Fprinter>

[100] Tomohiko Otsuka, "Yamaha Unmanned Helicopters Can Easily Be Converted to Military Use; Company Oblivious About Military Value," *Tokyo Sankei Shimbun*, August 6, 2006 (via Open Source Center JPP20060807036001). <https://www.opensource.gov/portal/server.pt/gateway/PTARGS_0_0_200_240_51_43/http%3B/apps.opensource.gov%3B7011/opensource.gov/content/Display/6282250?action=advancedSearch&highlightQuery=eJzT8AoIMDIwMDOwMDA3MDYzMDDUBAAqKAP9&fileSize=57894>

[101] Shinchi Kiyotani, "Japan Unveils Three Unmanned Vehicle Designs," *Jane's Defence Weekly*, November 9, 2005, 12.

[102] "Illegal Export of Unmanned Helicopters to China Reveals Gaps in Export Control Awareness in Japan," *International Export Control Observer*, no. 4 (February 2006): 4.

[103] "Robonic to Launch UAV Test Flight Centre in Finland," UVS Canada, September 12, 2005. <http://uvscanada.org/blog/?p=43>

1,000 to 5,000 square kilometers of uncontrolled airspace. Robonic's facility offers year-round flight operations and a basic airfield infrastructure where customers can develop and test UAV systems as well as train personnel in the remote control operation of UAVs.[104]

CONCLUSION

Miniature and micro-sized UAVs are being developed, designed, and deployed in many countries worldwide. China, France, Germany, Israel, Japan, the United Kingdom, and the United States are world leaders in small and micro UAVs, yet Italy, the Netherlands, Singapore, South Korea, and other countries are developing them as well. Mini and micro UAVs are being used for military applications such as ISR and will be used in EW and NCW missions in the future. In addition, mini and micro UAVs are being used in agriculture, meteorology, and disaster assistance. The creation of swarming networks of UAVs is also being studied around the world, led by China, Israel, the United Kingdom, and the United States. Technological innovations and research will continue to propel the capabilities and use of mini and micro UAVs.

[104] "Robonic to Launch UAV Test Flight Centre in Finland."

APPENDIX 1

The following is a listing of mini and micro UAVs produced in China, France, Germany, Israel, Italy, Japan, Jordan, the Netherlands, Norway, Russia, Singapore, South Korea, and Ukraine.

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
China											
ASN–15	China National Aero Technology Import and Export Corporation		6.5 kg MTOW	One hour endurance	Hand or rail launch, parachute recovery	6.5 kg payload, CCD camera			Real-time video data link or camera		Sales package includes three UAVs, remote control, navigation system, and video cassette recorder
France											
AZIMUTH 2 (in production)	ALCORE Technologies SA	Close-range surveillance	1.82 m length, 0.3 m height, 2.9 m wingspan, 9 kg MTOW	120 km/h, 300 m ceiling, 10 km mission radius, 60 km/h endurance speed	Hand or catapult, skid landing	2 kg payload, ILL or CCD on 2 axes	Auto pilot and GPS	600-W electric motor, Lithium polymer battery	Real-time video downlink, S band and analog	Epoxy Kevlar carbon composite	
EASY COPTER (in production)	ALCORE Technologies SA	Surveillance	0.65 m length, 0.65 m rotor diameter, 1.6 kg MTOW	0.15 hour endurance	Vertical takeoff and landing (VTOL)	Digital camera and daylight video camera	Flight control GPS and auto stabilization	Brushless 180-W electric motor, 12-V Lithium polymer batteries for electrical power		Composite with carbon and polyurethane drive belts	
EPSILON 1 (in development)	ALCORE Technologies SA	Close-range reconnaissance and surveillance	0.38 m length, 0.10 m height, 0.48 m wingspan, 0.45 kg MTOW	40 km/h, 0.1 hour endurance, 30 m ceiling, 1 km mission radius	Hand launch, skid recovery	Color CCD with real-time video downlink	Handle control, optical stabilization or piezo gyro	High air pressure piston engine	72 Mhz uplink, 400 Mhz downlink	Composite	

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
MAYA (in development)	ALCORE Technologies SA	Research and development	340 mm height, 320 mm rotor diameter, 2.5 kg MTOW	0.5 hour endurance, 1.5 km mission range	VTOL	0.5 kg max payload, CCD	Autonomous and GPS	600-W electric motor	Analog FM	Composite	
ODIN	Sagem		0.61 m wingspan, 0.41 m diameter, 3.18 kg MTOW	Lateral movement, hovers for 36 min, Ducted fan design	VTOL			Battery powered			
Germany											
ALADIN (in development)	EMT	Real-time surveillance, reconnaissance and target acquisition and location	1.4 m length, 1.5 m wingspan, 3 kg MTOW	45–90 km/h, 30 to 200 m ceiling, 5 km mission radius, 0.5 hour endurance	Hand launched, autonomous deep stall landing	0.3 kg payload, forward and downward looking color zoom CCD with optional low light and IR	Manual or autonomous GPS navigation with provision for autonomous return on loss of link	300-W electric motor, nickel metalhydride or lithium ion	Real-time imagery and control from uplink and downlink		
CAROLO P50 (in development)	Mavionics GmbH	Reconnaissance and surveillance	0.4 m length, 0.5 m wingspan, 550 g MTOW	74 km/h, 0.5 hour endurance, 457 m ceiling	Hand, skid recovery	Video camera	Mavionics Autopilot: GPS/INS-based flight control system with autonomous waypoint navigation and emergency management	50-W electric motor, Lithium polymer battery	Bi-directional data and command link with separate downlink for real-time imagery	Composite	

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
CAROLO P330 (in production)	Mavionics GmbH	Aerial photography	1.4 m length, 2.3 m wingspan, 5 kg MTOW	111 km/h, 1 hour endurance, 6,096 m ceiling	Hand, skid recovery	0.35 kg max payload, digital still camera with 7 megapixel resolution	Mavionics Autopilot: GPS/INS-based flight control system with autonomous waypoint navigation and emergency management	350-W electric motor, Lithium polymer battery	Bi-directional data and command link	Composite	
CAROLO T200 (in production)	Mavionics GmbH	Reconnaissance, surveillance, environmental and meteorological research, GN&C testbed	1.4 m length, 2 m wingspan, 5 kg MTOW	65 km/h, 1 hour endurance, 1,829 m ceiling	Hand, skid recovery	2 kg payload, visible/near IR video camera, meteorological wind vector, pressure, temperature, humidity	Mavionics Autopilot: GPS/INS-based flight control system with autonomous waypoint navigation and emergency management	Two 200-W brushless electric motors, Lithium polymer batteries	Bi-directional data & command link, separate downlink for real-time imagery, controlled by tablet PC	Composite	
DO–MAV (in development)	EADS Defence and Communications Systems–Dornier GmbH	Noiseless close-range reconnaissance for infantry and special forces	0.41m wingspan, 500 g MTOW	0.5 hour endurance, 1 nm mission radius	Hand, skid landing	Video camera and transmitter	GPS navigation and autonomous flight control system	Electric motor, accu pack	Real time		
FANCOPTER (in development)	EMT	Indoor/outdoor reconnaissance and surveillance	0.5 m rotor diameter, 1.5 kg MTOW	0.5 hour endurance, 500 m mission radius	VTOL	EO/IR	Full and semi-autonomous	Electric motor	Real-time video and telemetry	Composite	

Name of UAV	**Manufacturer**	**Uses**	**Size**	**Performance**	**Launch/ Recovery**	**Payload**	**Navigation**	**Power**	**Connectivity**	**Materials**	**Other Information**
MIKADO (in development)	EMT	Surveillance, reconnaissance, target acquisition and location in real time	0.46 m length, 0.49 m wingspan, 500 g MTOW	75 km/h, 0.5 hour endurance, 1 km mission radius	Hand or vertical, autonomous deep-stall landing	Daylight color and low-light black and white video	Autonomous GPS waypoint navigation or manual flight mode, autonomous return upon loss of data link	Electric motor	Up and down link for real-time imagery and control		
Israel											
BIRD EYE 100 (in development)	IAI Malat	Reconnaissance and surveillance	0.85 m wingspan, 0.80 m length, 1.3 kg MTOW	1 hour endurance, 5 km mission radius, 148 km/h max speed, 40 km/h loiter speed	Hand or bungee/ catapult	0.3 kg payload	Digital mapping	Electric motor			
BIRD EYE 500 (in development)	IAI Malat	Real-time day or night data imagery for police or military	1.6 m length, 2 m wingspan, 5 kg MTOW	111 km/h, 1 hour endurance, 10 km mission radius	Hand or bungee	Gimbaled video camera		Electric motor			
BOOMERANG V2 (in development)	BlueBird Aero System	Surveillance and reconnaissance	1.1 m length, 0.3 m height, 2.4 m wingspan, 5 kg MTOW	120 km/h, 2.5 hour endurance, 500 m ceiling	Hand or catapult, parachute recovery	1.2 kg payload, EO/IR with pan, tilt, and zoom	Autonomous	Electric motor			
CASPER (in development)	Top I Vision	Tactical surveillance and reconnaissance, special operations, law enforcement, perimeter security, target acquisition	1.7 m length, 2 m wingspan, 4.7 kg MTOW	70 km/h, 1.5 hour endurance, 250 m ceiling, 10 km mission radius	Hand, soft flair to belly landing	240 kg max payload, Earth observation/ infrared		Electric motor	Real-time video and telemetry data transmission	Composite	

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
I–SEE (in development)	IAI Malat	Short-range surveillance/ reconnaissance	1.82 m length, 2.9 m wingspan, 7.5 kg MTOW	1 hour endurance, 3,048 m ceiling	Hand	0.8 kg payload, Earth observation/ infrared					
MOSQUITO 1.5 (in development)	IAI Malat	Surveillance/ reconnaissance	34 cm wingspan, 500 g MTOW	One hour endurance, 1 km mission radius, 90 m operating altitude	Hand	Video camera		Electric motor			
ORBITER (in development)	Aeronautics Defense Systems Ltd.	Surveillance, reconnaissance, and target acquisition	1 m length, 0.3 m height, 2.2 m wingspan, 6.5 kg MTOW	139 km/h, 1.5 hour endurance, 4,572 m ceiling	Hand, catapult, or bungee with parachute or airbag recovery	1.5 kg max payload, DSTAMP, LSTAMP	UMAS avionics, real-time payload control, fully autonomous, in-flight programma-ble, camera-guided flight	Electric brushless motor	LOS (15 km range)	Composite	
SEAGULL (in development)	Elbit Systems Ltd. UAV Systems	Tactical surveillance and reconnaissance and special missions	0.80 m length, 2.14 m wingspan, 5.5 kg MTOW	74 km/h, 4-hour endurance, 10 km mission radius	Air launch or ground launch by hand or rail	CCD color sensor, FLIR sensor	Fully autonomous	Electric motor	Real-time continuous video and telemetry data transmission		Boomerang-shaped flying wing
SKYLARK IV (in production)	Elbit Systems Ltd. UAV Systems	Tactical surveillance, perimeter security, and law enforcement	2.2 m length, 2.4 m wingspan, 4.5 kg MTOW	111 km/h 1.5 hour endurance, 4,572 m ceiling, 10 km mission radius	Hand, deep-stall recovery	Color CCD, FLIR	Autonomous navigation	Electric motor	VSAT system with real-time live video transmission		
SKYLITE (in production)	RAFAEL	Surveillance, reconnaissance, and target acquisition	1.16 m length, 1.7 m wingspan, 6 kg MTOW	120 km/h, 1 hour endurance, 10 km mission radius	Canister, net recovery		GPS, INS			Composite	

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
Italy											
CORVO (in production)	International Aviation Supply	Surveillance	1.37 m length, 1.8 m wingspan, 7.7 kg MTOW	222 km/h, 4 to 8 hour endurance, 2,000 m ceiling	Compressed air catapult mounted on tripod or vehicle	6.8 kg max payload	Non-autonomous, semi-autonomous, or autonomous options	26 cc to 35 cc engine			
GABBIANO (in production)	International Aviation Supply	Surveillance	1.93 m length, 3.34 m wingspan, 4.5 kg MTOW	46 km/h, 2 plus hours endurance, 3,000 m ceiling	Hand	0.5 kg max payload	Non-autonomous, semi-autonomous, or autonomous options	Electric motor			
Japan											
RMAX (in production)	Yamaha Motor Company	Spraying pesticide reconnaissance, surveillance	3.115 m main rotor	72 km/h max speed, 20 km/h cruise speed, 2,000 m ceiling	VTOL	Digital camera, video camera, laser range-finder	Autonomous or remote control	246 cc gas engine (20.7 hp)			Helicopter with two rotors, flight stabilization. Military, observation, and agriculture versions.
Jordan											
I–WING	JARS		1.25 m wingspan, 1.05 m length	91 m operating altitude, 10 km mission radius, monoplane dual propeller pusher with V-tail	Solid rocket booster from tube	Dual daylight or low-light cameras in nose or forward-looking fixed IR	Autonomous takeoff, landing, and flight, GPS autopilot navigation	Electric motor, lithium battery	Eight-channel microwave downlink		

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
Netherlands											
DELFLY (in development)	Delft University of Technology	Swarming, reconnaissance, facial recognition to identify persons within crowds, urban scouting	35 cm wingspan, 17 g MTOW	6 km/h, flapping wing		Mini camera		Electric motor			
Norway											
RECCE D6 (in development)	CE Stephansen	Reconnaissance and surveillance	1.06 m length, 0.26 m height, 1.42 m wingspan, 2.8 kg MTOW	100 km/h, 0.55 hour endurance, 305 m ceiling, 10 km mission radius, 70 km/h endurance speed	Hand with skid landing	0.5 kg max payload, CCD video camera, IR camera	Remote control and GPS auto-navigation with Neural Network Adaptive Control, laptop computer mapping	200-W brushless motor, Lithium polymer battery	RF uplink/ downlink, real-time video downlink	Composite	
Russia											
IRKUT–2F and 2T	Irkut	Remote sensing	2 m wingspan, 0.3 kg payload, 2.8 kg MTOW	80 km/h cruising speed, 2,500 m ceiling, 40 km range, 1 hour endurance	Hand launch, belly landing	Digital camera, video camera, infrared camera	Automatic or manual control	Battery-powered electric motor		Composite	High monoplane design, no landing gear. 2F has autonomous flight, 2T has manual control.
Singapore											
FANTAIL (in development)	Singapore Technologies Aerospace	Close-range real-time reconnaissance in “constrained environments,” communications relays, and lethal weapons	720 mm length, 0.84 m height (including landing gear), 0.29 m rotor diameter, 3 kg MTOW	111 km/h, 1 hour endurance	VTOL	1 kg max payload, daylight or low-light video camera, uncooled IR cameras, microphones, biological/ chemical sensors	Automatic flight control system with GPS navigation			Carbon fiber composite airframe with modular construction	Cylindrical fuselage, ducted fan design.

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
FANTAIL 5000 (in development, production expected in 2007)	Singapore Technologies Aerospace	Close-range real-time reconnaissance, swarming	1.15 m length, 0.59 m diameter, 0.47 m rotor diameter, 5.5 kg MTOW	111 km/h, 30 min hover, 1 hr loiter in airplane mode	VTOL	0.49 kg payload, electro-optical or uncooled infrared sensors, forward- and downward-looking camera		3.5 hp two-stroke gas engine			Leans over to fly horizontally. Ducted fan design.
GOLDEN EYE (in development)	Cradence Services Pte Ltd	Surveillance	770 mm length, 650 mm wingspan, 850 g MTOW	1 hour endurance, 200 m ceiling, heart-shaped wing plan, 72 km/h max speed, 29 km/h minimum speed, 8.7 km mission radius	Pneumatic, hand, or catapult, deep-stall recovery	80 g max payload, camera, gas analyzer, microphone	Autonomous GPS utilizing waypoints	Brushless motor, rechargeable batteries	Airborne transceiver and antenna		
SKYBLADE II & III (in development)	Singapore Technologies Aerospace	Reconnaissance and surveillance	1.2 m length, 1.8 m wingspan	129 km/h, 2 hour endurance, 4,572 m ceiling	Hand or bungee, parachute recovery		Autonomous	II–piston-powered, III–battery-powered	Digital radio frequency		
South Korea											
SPOT	Kunkuk University	Reconnaissance	0.15 m wingspan, 1.8 m wing area, 68.5 g MTOW	36 km/h				Electric motor, Lithium-ion battery			Domestic, foreign marketing
Ukraine											
AIST–1	Kharkiv Aviation Institute	Reconnaissance and surveillance	1.2 m wingspan, 0.8 m length, 2 kg MTOW	10 km range, 1 hour endurance	Hand launch, deep-stall landing	0.3 kg payload, optional low-light level video camera or NBC detector		150-W electric motor	Ground data link with antennas	Composite	V-tail, tractor propeller, notebook PC flight control. Modular airframe. Two AIST–1s sold as system.

Name of UAV	**Manufacturer**	**Uses**	**Size**	**Performance**	**Launch/ Recovery**	**Payload**	**Navigation**	**Power**	**Connectivity**	**Materials**	**Other Information**
ALBATROSS–4	Scientific Industrial Systems	Reconnaissance and surveillance	2 m wingspan	2 hour endurance	Wheeled takeoff/ parachute landing	3 kg payload	GPS				
BEKAS	Kharkiv Aviation Institute	Reconnaissance and surveillance, target acquisition	1.9 m wingspan, 1.6 m length, 20 kg launch weight	60 km range, 4 hour endurance, 170 km/h max speed, 120 km/h cruise speed	Wheeled or catapult launch, wheeled or parachute landing	Day and night video cameras, infrared scanner, EW	Autonomous, GPS navigation or remote control	3 hp gas engine	Ground data link with antennas	Fiber glass	Modular airframe. Four BEKAS sold as system.
REMEZ–3	Scientific Industrial Systems	Reconnaissance and surveillance	2 m wingspan, 10 kg MTOW, 3 kg payload	105 km/h max speed, 5 km control range, 2 hour endurance	Wheeled or catapult launch/ parachute recovery	Video cameras	Remote control	2.5 hp gas engine	Real-time downlink		Shrouded pusher propeller

Sources: Based on information from “AIST Unmanned Aerial Surveillance System,” Kharkiv Aerial Surveillance System <http://www.khai.edu/niipfm/english/aist-en.htm>; “ASN 15 UAV,” Northwest Polytechnical University Web site, n.d. <http://www.nwpu.edu.cn/departments/365/asn-15.htm> (accessed 8/16/2006); “ASN–15 Unmanned Reconnaissance Aerial Vehicle,” *sinodefence.com* Web site, May 27, 2006 <http://www.sinodefence.com/airforce/uav/asn15.asp>; “Delft University to Expand DelFly MAV Capability for Security Work,” *Jane’s International Defence Review*, April 2006, 34; “Ducted-Fan UAVs Go Global,” *Aviation Week & Space Technology*, July 31, 2006; Greg Goebel, “Miniature UAVs,” Greg Goebel / In the Public Domain <http://www.vectorsite.net/twuav_17.html>; *Jane’s Unmanned Aerial Vehicles and Targets*, January 4, 2006 <http://www.janes.com>; “ST Aero Presses on with MAV-1,” *Flight International*, February 28, 2006 <http://www.flightglobal.com>; and *Unmanned Vehicles Handbook 2006* (Bucks, UK: The Shepard Group, December 2005).

APPENDIX 2

The following is a partial listing of mini and micro UAVs manufactured in Australia, South Africa, the United Kingdom, and the United States. They are provided here to serve as a reference point for UAVs from other countries.

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
Australia											
AEROSONDE MARK 4.1	Aerosonde	Meteorology, electronic warfare	2.9 m wingspan	115 km/h max speed, 91 km/h cruising speed, 15 kg MTOW	Car roof rack or catapult launch, belly landing	Meteorology instruments, EW, IR sensor, video, still cameras	Fully autonomous, GOS, DGOS navigation	1.75 hp engine	Loral/Conic CRI–400 series 9600-band UHF modem. 25-kHz channel, Satcom link		Inverted v-tail, pusher design. Mark 1 was first UAV to fly across Atlantic Ocean on August 17, 1998.
MANTIS	CSIRO	Autonomous flight test vehicle	1.52 m rotor diameter, 8 kg MTOW	18 minute endurance	VTOL	75 g payload, video cameras		Piston engine		Aluminum alloy	Based on hobby aircraft. Rotary wing, two blades.
South Africa											
LARK	Denel	Jamming, decoy, attack, and reconnaissance	2.1 m wingspan, 2.4 m length, 120 g MTOW	210 km/h cruise speed, 129 km/h loiter speed, 4,575 m ceiling	Rocket assist or container launch, parachute and airbag recovery	TV camera, thermal imager	Two-axis gyro, satellite navigation	38 hp rotory engine		Composites	Mid-wing double delta design
United Kingdom											
BUSHMASTER (in development)	Cyberflight	Reconnaissance and surveillance	2 m wingspan, 2 kg MTOW	129 km/h max speed, 1.5 hour endurance	Hand launch/ parachute recovery	250 g payload, cameras on wing and body	GPS		Multi 4-channel microwave downlink		
CYBERONE	Cyberflight	Reconnaissance and surveillance	1.69 m wingspan, 5.4 kg empty weight	160 km/h max speed, 57 km/h cruise speed, 6,100 m ceiling, 32 km range, 2 hour endurance	Wheeled takeoff and landing	6.8 kg payload	GPS navigation		D-band (1.3-GHz) data link		Twin-wing design. Twin-engine: one tractor, one pusher.

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
FAN WING–B	Fan Wing	Reconnaissance, surveillance, remote sensing, mine detection	1.4 m wingspan (rotorspan), 6 kg MTOW	75 km/h max speed	Wheeled takeoff and landing		Remote controlled	4.5 cc glow plug engine			Experimental fan-wing design featuring multi-blade, backward-rotating cylinders. Experimental design with low-stall speed.
SWIFT-EYE A and B	Cyberflight	Reconnaissance and surveillance	A: 1.42 m wingspan, B: 1.52 m wingspan A: 1.8 kg, B: 2.3 kg	145 km/h max speed, 48 km/h cruise speed, A: 40 minute endurance, B: 1 hour endurance	Hand launch, parachute recovery	Video camera with real-time downlink, infrared or film camera	Remote control with automatic return home feature	Piston engine			Swept-wing design.
United States											
BACKPACK	Mi-Tex		1.2 m wingspan, 4.8 kg MTOW	3,000 m ceiling, 2 hour endurance	Bungee catapult from rail/parachute recovery	1.4 kg payload, EO/IR	Autonomous	Single-piston engine	GCS monitors UAV progress and imagery		Twin-wing design—wings joined at tips
BAT	MLB	Surveillance	1.83 m wingspan, 8.6 kg MTOW	111 km/h max speed, 35 kt cruising speed, 2,745 m ceiling, 9.7 km radius, 322 km range, 4 hour endurance	Vehicle or hand launch/ parachute or wheeled landing	1.8 kg payload, CCD camera, 900 MHz two-way modem, S-band, video downlink	Autonomous or manual			Kevlar, carbon fiber, and aluminum	Pusher-propeller design
BLACK WIDOW (in development)	AeroVironment Inc.	Close-range reconnaissance	0.23 m wingspan, 56 g MTOW	56 km/h, 61 m ceiling	Hand launch, belly landing	15 g payload max. Color CCD camera with downlink	Remote control	10-W electric motor	Radio control uplink and live video downlink	Composite	
BUSTER	Mission Technologies	Reconnaissance and surveillance	1.22 m wingspan, 4.08 kg weight, 4.54 kg MTOW	120 km/h max speed, 35 kt cruising speed, 2 hour endurance, 3,048 m ceiling, 15 km radius	Catapult or wheeled launch/ parachute or wheeled landing	EO/IR or lowlight CCD	GPS	1.6 hp 2-stroke engine	C-band, 900 MHz for command	Composite carbon	Twin-wing

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
CYBER BUG	Cyber Defense Systems	Surveillance	1.4 m wingspan, 3.4 kg MTOW	55 km/h cruise speed, 1.5 hour endurance	Hand launch, skid recovery	1.13 kg payload	Autonomous	Battery			Parafoil wing
CYPHER	Sikorsky	Recon. and surveillance	1.89 m diameter, 1.2 m rotor diameter, 75 kg empty weight, 113 kg MTOW	129 km/h cruising speed, 2,440 m ceiling, 30 km radius, 2.5 hour endurance	VTOL	Cameras, thermal imagers, acoustic sensors	GPS, semi-autonomous speed and altitude input	Rotary engine with 52 hp		Composite graphite and epoxy	VTOL, two four-blade counter-rotating rotors
DESERT HAWK FPASS (in production)	Lockheed Martin	Force protection, reconnaissance, and surveillance	1.32 m wingspan, 3.18 kg MTOW	1 hour endurance, 152.4 m ceiling	Bungee launch, automatic landing	EO/IR	Autopilot		US military frequencies	Foam	Pusher design
DRAGON EYE (in production)	AeroVironment Inc.	Surveillance	1.22 m wingspan, 1.81 kg empty weight, 2.27 kg MTOW	74 km/h max speed, 64 km/h cruise speed, 1 hour endurance, 305 m ceiling, 8 km radius	Hand or bungee launch, deep-stall or parachute landing	0.45 kg payload	GPS	240-W battery, dual brushless electric motor	RF modem	Kevlar/ epoxy	Twin-propeller design
EVOLUTION (XT)	L–3 Communications Corp	Reconnaissance and surveillance	1.22 m wingspan, 3.4 kg MTOW	72.42 km/h max speed, 35 kt cruise speed, 152.4 m ceiling, 8 km radius	Hand or bungee launch, deep-stall or parachute recovery	Chem or bio detectors, infrared cameras, comm relay package	GPS and autopilot	Lithium battery, two Aveox electric motors	4-channel UHF uplink receiver and antenna, 4-channel microwave transmitter and antenna		Twin-propeller design
GOLDENEYE–50 (in development)	Aurora Flight Sciences Corp.	Reconnaissance, surveillance	1.37 m wingspan, 0.29 m rotor duct diameter, 7.3 kg MTOW	1 hour endurance at 185 km/h, 1,524 m ceiling	VTOL	1.4 kg payload, bio and chemical sensors		5 hp		Graphite and fiberglass composite	Barrel-shaped

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
HORNET	AeroVironment Inc.		0.38 m wingspan, 170 g MTOW	5 min endurance	Hand launch/ belly landing		Manual radio control	10-W electric motor, hydrogen fuel cell			Testing flying-wing design and materials
IAV2 (in development)	BAE Systems, USA	Surveillance	56 cm diameter ducted-fan shroud, 57 kg MTOW	4 hour endurance, 30.5 m ceiling	VTOL	8.8 kg payload, EO	Autonomous				Ducted-fan design
INVENTUS E	Lew Aerospace	Reconnaissance, remote delivery	1.8 m wingspan, 2.3 kg MTOW	48 kt cruising speed	Hand, vehicle, or catapult launch/ belly or parachute landing		Autopilot or microwave control	Lithium polymer batteries	Microwave	Composite	Flying-wing design
ISTAR (in development)	Allied Aerospace	Reconnaissance, surveillance, target acquisition	0.74 m ducted fan diameter, 29.5 kg MTOW	185 km/h, 10 km range, 1.5 hour endurance	VTOL	9.1 kg payload, electronic observation (EO), video cameras, acoustic sensors	Autonomous, including takeoff and landing	2-stroke gas engine		Carbon fiber and epoxy	Ducted-fan design, upper and lower payload bays within ducted-fan shroud
KILLERBEE–2	Northrup Grumman	Reconnaissance	1.98 m wingspan	108 kt max speed, 59 kt cruising speed, 5,480 m ceiling, 93 km radius, 24 hour endurance	Pneumatic or aircraft launch/net or skid recovery	EO, IR, laser rangefinder, hyperspectoral sensor	PDA or laptop control or autonomous flight				Flying-wing design
MAV (in development)	Honeywell	Surveillance	0.33 m diameter ducted-fan shroud, 6.8 kg MTOW	4 hour endurance, 3,200 m ceiling	VTOL	0.91 kg payload	GPS				Ducted-fan design
MICROSTAR (in development)	BAE Systems, USA	Surveillance	0.15 m wingspan, 0.14 kg MTOW	48 km/h, 0.2 hour endurance, 91.5 m ceiling	Hand launch/ belly landing	Digital video camera, IR, bio or chem sensors	Autonomous		Digital spread spectrum data link		Real-time imagery, flying-wing design

Name of UAV	Manufacturer	Uses	Size	Performance	Launch/ Recovery	Payload	Navigation	Power	Connectivity	Materials	Other Information
MITE–2B	Naval Research Lab, U.S. Navy		0.36 m wingspan, 0.21 kg MTOW	32.19 km/h, 20 minute duration	Hand launch	Color video camera		Two 7-W motors, 12-V battery	FM 72 MHz		
RAVEN (in production)	AeroVironment Inc.	Surveillance and reconnaissance	1.3 m wingspan, 1.8 kg empty weight, 2 kg MTOW	96 km/h max speed, 50 km/h cruising speed, 2 hour endurance, 150 m ceiling, 10 km radius	Hand launch, vertical descent autoland	0.2 kg payload, color video, IR	GPS, auto navigation	Brushless DC 200-W battery	RF uplink/ downlink	Kevlar composite	
SEA FERRET	Northrup Grumman	Reconnaissance	1.83 m wingspan, 68 kg MTOW	250 kt max speed, 6,100 m ceiling, 600 km range, 3 hour endurance	Underwater or surface launch by booster rocket/ parachute recovery	Camera with real-time downlink		Turbojet			
SOAR and SWITCHBLADE (in development)	AeroVironment Inc.	Surveillance, reconnaissance, target acquisition	0.6 m wingspan	140 km/h max speed, 0.8 hour endurance, 3,000 m ceiling	Mortor- or gun-launched (120 mm or 105 mm)/ net recovery	3 EO cameras, 1 IR camera	Autonomous GPS	Electric motor	AV Raven RF link		Can glide or use electric motor after ballistic launch
WASP (in development)	AeroVironment Inc.	Surveillance and reconnaissance	36 cm wingspan, 170 g MTOW	150 km/h, 1 hour endurance, 300 m ceiling	Hand launch/ glide descent	15 g payload, two-color video cameras	Autonomous GPS or manual control	143-W Lithium-ion	AV Raven RF Link	Composite	Rectangular flying-wing design

Sources: Based on information from *Jane's Unmanned Aerial Vehicles and Targets*, January 4, 2006 <http://www.janes.com>; James Kellogg, Christopher Bovais, Jill Dahlburg, Richard Foch, John Gardiner, Diana Gordon, Ralph Hartley, Berhooz Kamgar-Parsi, Hugh McFarlane, Frank Pipitone, Ravi Ramamurti, Adam Sciambi, William Spears, Donald Srull, and Carol Sullivan, "The NRL Mite Air Vehicle," Proceedings of the Bristol RPV/AUV Systems Conference, Bristol, United Kingdom, March 30–April 1, 2001 <http://www.cs.uwyo.edu/~wspears/papers/nrl.mite.pdf>; and *Unmanned Vehicles Handbook 2006* (Bucks, UK: The Shepard Group, December 2005).

BIBLIOGRAPHY

Abershitz, Avi, David Penn, Amit Levy, Aviv Shapira, and Zvi Shavit. "IAI's Micro/Mini UAV Systems-Development Approach." September 2005 (AIAA 2005–7034).

AC Propulsion. "AC Propulsion SoLong UAV Flies for 48 Hours on Sunlight. Two Nights Aloft Opens New Era of Sustainable Flight." <www.acpropulsion.com/ACP_DOCs/ACP_SoLong_UAV_48hr_Flight_2005-06-05.doc>

"AeroVironment Flies World's First Liquid Hydrogen Powered UAV; Enables Persistent Communications Relay and Remote Sensing Breakthrough Systems; AeroVironment Flies World's First Liquid Hydrogen Powered UAV." *Business Wire*, June 28, 2005, 1 (via ProQuest ID: 860034331).

"AIST Unmanned Aerial Surveillance System." Kharkiv Aviation Institute Web site, n.d. <http://www.khai.edu/niipfm/english/aist-en.htm> (accessed 10/24/2006)

Altshuler, Yaniv, Vladimir Yanovsky, Isreal A. Wagner, and Alfred M. Bruckstein. "The Cooperative Hunters—Efficient Cooperative Search for Smart Targets Using UAV Swarms." <http://www.cs.technion.ac.il/people/yanival/online-publications/UAVs.pdf>

Altshuler, Yaniv, Vladimir Yanovsky, Isreal A. Wagner, and Alfred M. Bruckstein. "Swarm Intelligence-Searchers, Cleaners and Hunter." <http://www.cs.technion.ac.il/people/yanival/online-publications/SI-Book2006.pdf>

"ASN–15 Unmanned Reconnaissance Aerial Vehicle." *Chinese Defence Today*, May 27, 2006. <http://www. sinodefence.com/airforce/uav/asn15.asp>

"ASN 206 Unmanned Aerial Vehicle." *Chinese Defence Today*, October 19, 2006. <http://www.sinodefence.com/airforce/uav/asn206.asp>

Atair Aerospace. "Atair Aerospace Becomes First to Demonstrate Flocking and Swarming Capabilities." March 3, 2005. <http://www.atairaerospace.com/press/2005/03/atair-aerospace-becomes-first-to.html>

"Bekas Unmanned Aerial Surveillance System." Kharkiv Aviation Institute Web site, n.d. <http://www.khai.edu/niipfm/english/bekas-en.htm> (accessed 10/24/2006).

"Belgium Resumes Congo UAV Operations After B-Hunter is Shot Down." *Flight International*, August 14, 2006. <http://www.flightglobal.com/Articles/2006/08/14/Navigation/177/208465/Belgium+resumes+Congo+UAV+operations+after+Hunter-B+is+shot.html>

Banks, David P. "Fuel Cells: Powerful Implications." *Air & Space Power Journal* 18 (Spring 2004): 61 (via ProQuest ID: 627749981).

Bannon, David, and David Thomas. "Harsh Environments Dictate Design of Imaging Spectrometer." *Laser Focus World* 41 (August 2005): 93–96 (via ProQuest ID: 887487571).

"BirdEye 500 Backpackable UAV." *Defense Update*. <http://www.defense-update.com/products/s/spythere.htm>

Bowes, Peter. "High hopes for Drones in LA Skies." *BBC News*, June 6, 2006. <http://news.bbc.co.uk/2/hi/americas/5051142.stm>

Brewster, Carlyle C., Erin L. Holden, and Jon C. Allen. "Spatial Tools for Pest Management." *Geospatial Solutions* 12 (June 2002): 26–32 (via ProQuest ID: 122465061).

Bushmann, Marco. "MMAV–A Miniature Unmanned Aerial Vehicle (Mini–UAV) for Meteorological Purposes." <http://ams.confex.com/ams/BLTAIRSE/techprogram/paper_77875.htm>

Cortelazzo, Guido Maria, Adrian F. Clark, and John C. Woods. "Flocking of UAVs Software Model and Limited Vision Simulations." <http://privatewww.essex.ac.uk/~rdenar/De_Nardi_Renzo2005thesis.pdf#search=%22Flocking%20of%20UAVs%20Software%20Model%20and%20Limited%20Vision%20Simulations%22>

David, Alon Ben, Robert Hewson, Damian Kemp, and Stephen Trimble. "Special Report: UAVs-Frontline Flyers." *Jane's Defence Weekly*, May 4, 2006.

"Delft University to Expand DelFly MAV Capability for Security Work." *Jane's International Defence Review*, April 2006, 34.

"Denel Aerospace UAVs." Denel Web site, n.d. <http://www.denel.co.za/Aerospace/UAV.asp>

"Ducted-Fan UAVs Go Global." *Aviation Week & Space Technology* 165 (July 31, 2006).

Finn, Anthony, Kim Brown, and Tony Lindsay. "Miniature UAV's & Future Electronic Warfare." Government of Australia, Defence Science and Technology Organisation (accessed October 1, 2006). <http://www.aerosonde.com/downloads/Aerosonde_DSTO_EW.pdf>

Fulgham, David A. "Antenna Angst." *Aviation Week & Space Technology* 163 (October 24, 2005).

Furfaro, Roberto. "Radiative Transport in Plant Canopies: Forward and Inverse Problem for UAV Applications." PhD Dissertation (via Proquest ID: 845740481).

Genuth, Iddo. “Artificial Flock Will Hunt Terrorists.” *IsraCast-Israeli Technology News*. February 25, 2005. <http://www.isracast.com/Articles/Article.aspx?ID=73>

Goebel, Greg. “Miniature UAVs.” Greg Goebel / In the Public Domain. <http://www.vectorsite.net/twuav_17.html>

Goode, Barbara G. “Funding Enables UAV Capabilities.” *Sensors Magazine Online*. <http://mil.sensorsmag.com/sensorsmil/article/articleDetail.jsp?id=316635&searchString=funding%20enables%20uav%20capabilities>

Government of Australia. “Department of Defense, Defense Science and Technology Organization.” *Velocity Magazine*, December 2004. <http://velocity.ansto.gov.au/velocity/ans0003/article_02.asp>

Hillyer, Greg. “Sky Scouts.” *Progressive Farmer* (Southeast edition) [Birmingham], October 2003, SP8 (via ProQuest ID: 446208981).

Han, Su-Cheol, and Hyochoong Bang. “Proportional Navigation-Based Optimal Collision Avoidance for UAVs.” 2d International Conference on Autonomous Robots and Agents, December 13–15, 2004. <http://www-ist.massey.ac.nz/conferences/icara2004/files/Papers/Paper13_ICARA2004_076_081.pdf#search=%22Proportional%20Navigation-Based%20Optimal%20Collision%20Avoidance%20for%20UAVs%22>

“Helicopter Suppliers Court Poland’s Defence Industry.” *Jane’s Online*, September 14, 2006. <www.janes.com>

Holland, Owen, John Woods, Renzo De Nardi, and Adrian Clark. “Beyond Swarm Intelligence: The Ultraswarm.” IEEE Swarm Intelligence Symposium SIS2005. <http://cswww.essex.ac.uk/staff/owen/SIS2005copyright.pdf#search=%22%22beyond%20swarm%20intelligence%3A%20the%20ultraswarm%22%22>

Hu Zhenbiao, He Jun, and Liu Yaqi. “Simulation Study on Anti-Radiation Unmanned Aerial Vehicle Operations.” Beijing Junshi Yunchou Yu Xiton Gongcheng, December 1, 2005 (via Open Source Center CPP20060315424005).

Hwang, Soojung, Yushin Kim, Myeong Kyu Lee, and Jai Moo Kim. “Tilt Rotor/Wing Concept for Multi-Purpose VTOL UAV.” [Taken from abstract of report.] <http://erf32.nlr.nl/abstracts/pdf/UA01.pdf#search=%22%22tilt%20rotor%2Fwing%20concept%20for%20multi-purpose%20vtol%20uav%22%22>

“Illegal Export of Unmanned Helicopters to China Reveals Gaps in Export Control Awareness in Japan.” *International Export Control Observer*, no. 4 (February 2006): 4.

“India’s Defense Market May Be Tougher Than Israel Thinks.” *Defense Daily International* 7, no. 20 (May 2006): 1 (via ProQuest ID: 1040097731).

"IntelliTech's Vector P Completes Successful Agricultural Test Flight." *Business Wire*, October 4, 2005 (via ProQuest).

"Israel Media Assess Hizballah Use of UAVs in Lebanon Conflict," August 8, 2006 (via Open Source Center FEA20060809026111).

"Israel Sells Heron UAVs to India, Australia," November 11, 2005. <http://www.defenseindustry.com>

"Israel: Roundup of Defence Industries' Deals, Innovations 25 Jun–6 Jul 06," July 8, 2006 (via Open Resource Center GMP20060708740005).

Jane's Unmanned Aerial Vehicles and Targets," January 4, 2006. <http://www.janes.com>

Jaquish, Major Douglas W. "Uninhabited Air Vehicles for Psychological Operations-Leveraging Technology for PSYOP Beyond 2010." *Air & Space Power Journal*, April 6, 2004. <http://www.airpower.maxwell.af.mil/airchronicles/cc/jaquish.html>

Karniol, Robert. "Pakistan Opts for European UAVs." *Jane's Defence Weekly*, March 15, 2006, 16.

Kellogg, James, Christopher Bovais, Jill Dahlburg, Richard Foch, John Gardiner, Diana Gordon, Ralph Hartley, Berhooz Kamgar-Parsi, Hugh McFarlane, Frank Pipitone, Ravi Ramamurti, Adam Sciambi, William Spears, Donald Srull, and Carol Sullivan. "The NRL Mite Air Vehicle." Proceedings of the Bristol RPV/AUV Systems Conference, Bristol, United Kingdom, March 30–April 1, 2001. <http://www.cs.uwyo.edu/~wspears/papers/nrl.mite.pdf>

Kemp, Ian. "Controlling Drones at War." *Armada International* [Zurich] 30, no.1 (February/March 2006): 26 (via ProQuest).

Kim, Cheol Wan, Sang Oh Chu, Pyonghee Chang, and Jin Duk Chung. "The Research on Aerodynamic Database for Real Time Flight Simulation of the Tilt-Rotor UAV." <http://aero.kari.re.kr/korean/paper/RP/ADG-RP-2004-028.PDF>

Kim, C.W., Y.M. Park, B.H. Chang, and J.Y.Lee. "Analysis of Tilt-Rotor Aircraft with Power Effect." The 6th Asian Computational Fluid Dynamics Conference, October 24–27, 2005. <http://aero.kari.re.kr/Korean/Paper/RP/ADG-RP-2005-022.pdf>

Kivelevitch, Elad, and Pini Gurfil. "Taxonomy of Mission Performance for Diverse and Homogenous UAV Flocks." AIA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005, San Francisco (AIAA 2005–5828).

Kiyotani, Shinchi. "Japan Unveils Three Unmanned Vehicle Designs." *Jane's Defence Weekly*, November 9, 2005, 12.

Korea Aerospace Research Institute. "Aeronautics Smart UAV Development Program." <http://www.kari.re.kr/english/pro/pro_01_01.asp?show=21>

Korean Aeronautical Research Institute. <http://www.kari.re.kr/>

La Franchi, Peter. "BAE Plans Swarming UCAV Demo; UK Company's Australian Unit and DSTO Study Joint Programme to Test Advanced UAV Reconnaissance Technologies." *Flight International*, February 24, 2004.

La Franchi, Peter. Denel Develops Mini-UAV for Medical Courier Ops. *Flight International*, June 9, 2006. <http://www.flightglobal.com/Articles/2006/09/25/Navigation/326/209218/Denel+develops+mini-UAV+for+medical+courier+ops.html>

La Franchi, Peter. "South Africa's UAV Duo ATE and Denel in Merger Talks." *Flight Global*, September 25, 2006. <http://www.flightglobal.com/Articles/2006/09/25/Navigation/326/209215/South+Africa's+UAV+duo+ATE+and+Denel+in+merger+talks.html>

Legler, David. "Electronic Warfare Capabilities of Mini UAVs." <www.aerosonde.com/downloads/electronic_warfare_ledger.doc>

Li Shouan, Zhang Hengxi, Guo Feng, and Li Dengke. "Actuality, Development Trend of Micro Air Vehicles." *Beijing Daodan Yu Hangtian Yunzai Jishu*, June 1, 2005 (via Open Source Center CPP20060518324002).

Liu Chang'an, Liang Guangping, Wang Heping, and Li Wieiji. "PRC S&T: Application of Ant Algorithm to Path Planning to Reconnaissance UAV." *Taiyuan Huli Yu Zhihui Kongzhi* [ShanXi, China], October 1, 2005 (via Open Source Center ID: CPP20060308424002).

Lim, Cheolho. "The Technology Trends of Unmanned Aerial Vehicle [UAV] and Smart UAV Development Program," August 13, 2004. <http://www.ksea.org/ukc2004/en/Proceedings/01AST/AST24_CheolhoLim.pdf#search=%22The%20Technology%20Trends%20of%20Unmanned%20Aerial%20Vehicle%20%5BUAV%5D%20and%20Smart%20UAV%20Development%20Program%22>

Mahon, Tim. "Taking Off; Australian Industry Grows with UAV Needs." *C4ISR Journal*, June 1, 2006 (via Lexis–Nexis).

Maurer, John. "Polar Remote Sensing Using an Unpiloted Aerial Vehicle (UAV)." <http://cires.colorado.edu/~maurerj/class/UAV/aerosonde.htm>

Miasnikov, Eugene. "Terrorists Develop Unmanned Aerial Vehicles," December 6, 2004. <http://www.armscontrol.ru/UAV/mirsad1.htm>

Miasnikov, Eugene. "Terrorist Mini-UAVs: Technical Assessment of Capabilities," July 14, 2004. 16th Summer Symposium on Science and World Affairs, Beijing, July 17–25, 2004. <http://www.armscontrol.ru/UAV/miasnikov-ss16_files/frame.htm>

Miasnikov, Eugene. “Threat of Terrorism Using Unmanned Aerial Vehicles: Technical Apsects.” Moscow Institute of Physics and Technology. <http://www.armscontrol.ru/UAV/UAV-report.pdf>

Mouret, Jean Baptiste, Stephane Doncieux, and Jean-Arcady Meyer. “Incremental Evolution of Target-Following Neural Controllers for Flapping Wing Animats.” Animat Lab, Paris University, 2006. <http://people.happycoders.org/mandor/slides_sab.pdf>

Munson, Kenneth. “ST Aero FanTail.” *Jane’s Unmanned Aerial Vehicles and Targets*, May 21, 2004. <http://www4.janes.com/subscribe/juav/doc_view.jsp?K2DocKey=/content1/janesdata/binder/juav/juav9492.htm@current&Prod_Name=JUAV&QueryText=%3CAND%3E%28%3COR%3E%28%28%5B80%5Dvtol+%3CIN%3E+body%29%2C+%28%5B100%5D+%28%5B100%5Dvtol+%3CIN%3E+title%29+%3CAND%3E+%28%5B100%5Dvtol+%3CIN%3E+body%29%29%29%29>

Murphy, James. “BAE Systems Air Division to Refocus on UAVs.” *Jane’s Defence Weekly,* May 31, 2006.

National Aeronautic and Space Administration. “From Gas-Powered to Laser-Powered! NASA Research Team Successfully Flies First Laser-Powered Aircraft.” October 9, 2003. <http://www.nasa.gov/centers/marshall/news/news/releases/2003/03-180.html>

National Oceanic Atmospheric Administration. “Final Report: First-Ever Successful UAS Mission into a Tropical Storm (Ophelia - 2005).” <http://uas.noaa.gov/demonstrations/aerosonde/Ophelia_final.html>

Opall-Rome, Barbara. “UAV Finds Flaw in Israeli Air Defenses,” April 18, 2005. <http://www.isrjournal.com/story.php?F=792603>

O’Sullivan, Arieh. “IAI Having a Field Day at the Paris Air Show.” *Jerusalem Post*, June 19, 2005 (via ProQuest ID: 856063441).

Otsuka, Tomohiko. “Yamaha Unmanned Helicopters Can Easily Be Converted to Military Use; Company Oblivious About Military Value.” *Tokyo Sankei Shimbun*, August 6, 2006 (via Open Source Center JPP20060807036001).

Pardesi, Manjeet Singh. “UAVs/UCAVs-Missions, Challenges, and Strategic Implications for Small and Medium Powers.” *Institute of Defence and Strategic Studies*, May 2004. <http://www.idss.edu.sg/publications/WorkingPapers/WP66.PDF>

Pardesi, Manjeet Singh. “Unmanned Aerial Vehicles/Unmanned Combat Aerial Vehicles: Likely Missions and Challenges for the Policy-Relevant Future” *Air & Space Power Journal*, Fall 2005. <http://www.airpower.maxwell.af.mil/airchronicles/apj/apj05/fal05/pardesi.html>

Park, Chang-Su, Min-Jea Tahk, and Hyochoong Bang. "Multiple Aerial Vehicle Formation Using Swarm Intelligence." AIAA Guidance, Navigation, and Control Conference and Exhibit, August 11–14, 2003 (AIAA 2003–5729).

"Pipeline Control." Tactical Aerospace Group. <http://www.tacticalaerospacegroup.com/pipeline_patrol_inspection.html>

Plantcro Hobbies. "Lightweight Batteries with Superior Energy Density." <http://www.plantraco.com/hobbies/product-lpcells.html>

Public Broadcasting Service. "Spies that Fly," November 2002. <http://www.pbs.org/wgbh/nova/spiesfly/uavs.html>

Reynolds, C. "Flocks, Herds, and Schools: A Distributed Behavior Model." *Computer Graphics* 21 (July 1987): 25–34.

Rheinmetall Defence Electronics. "Electronic Warfare Attack/Support." <http://www.rheinmetall-detec.de/index.php?fid=2376&lang=3&pdb=1>

Rhem, Kathleen T. "Iraqi Plane Shoots Down American Predator Unmanned Aircraft." *Armed Forces Information Service*, December 23, 2002. <http://www.defenselink.mil/news/Dec2002/n12232002_200212236.html>

Ribaud, Yves, and Olivier Dessornes. "Micropropulsion Microcombustion." Aerospace Research and Technology [France], September 24, 2002. <http://www.onera.fr/conferences/micropropulsion/>

"Robonic to Launch UAV Test Flight Centre in Finland." <http://uvscanada.org/blog/?p=43>

Romero, Giulio, and Giacomo Frulla. "HELIPLAT: Aerodynamic and Structural Analysis of HAVE Solar Powered Platform." AIAA's First Technical Conference and Workshop on Unmanned Aerospace Vehicles, May 20–23, 2002, Portsmouth, Virginia (AIAA 2002–3504).

"Science and Technology: High Times; Future of Flight." *The Economist* [London], December 13, 2003 (via ProQuest ID: 499922401).

"Scientific Industrial Systems, Ltd." Construction Bureau Assent <http://vzlet.com.ua/index_english.html> (Accessed 11/9/2006).

Sheremet, Igor. "Network Centric Warfare: Origins and Technical Aspects." *Voyenno-Promyshlennyy Kuryer* [Moscow], February 22, 2006 (via Open Source Center CEP20060221436014).

Shouan, Li, Zhang Hengxi, Guo Feng, and Li Dengke. “Actuality, Development Trend of Micro Air Vehicles.” *Beijing Daodan Yu Hangtian Yunzai Jishu*, June 1, 2005, 56–59 (via Open Source Center ID: CPP20060518324002).

“Singapore Sets the Pace.” *Global Defence Review*. <http://www.global-defence.com/2001/RSpart3b.html>

“ST Aero Presses on with MAV-1.” *Flight International*, February 28, 2006. <www.flightglobal.com>

Stock, Kyle. “Robot-Copter Venture Taking Off.” *Post and Courier*, February 28, 2005 (via ProQuest ID: 800250881).

Stoil, Rebecca Anne. “Man Questioned for Illegal UAV Sales.” *The Jerusalem Post*, May 22, 2006. <http://www.jpost.com/servlet/Satellite?cid=1148287839566&pagename=JPost%2FJPArticle%2Fprinter>

Strata Technologies. “Don’t You Wish Your UAV Could Do This?” <http://www.medicalresupply.com/>

Sujit, P.B., and Debasish Ghose. “Search by UAVs with Flight Time Constraints Using Game Theoretical Models.” AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005, AIAA 2005–6241.

Taverna, Michael A., and Robert Wall. “Booster Shot.” *Aviation Week & Space Technology*, April 11, 2005 (via ProQuest ID: 821955281).

“Teal Group Predicts Worldwide UAV Market Will Top $54 Billion, Tripling in Spending Over the Next Decade.” *Shepard UVOnline*, August 31, 2006. <http://www.shepard.co.uk/UVOnline/Default.aspx?Action=-187126550&ID=e2fc1262-9e46-44d4-bec4-723e2c46d539>

Tsourdos, Antonio, Brian A. White, and Rafael Zbikowski. “Verifying UAV Path Planning: A Formal Approach of Choice.” <http://www.csc.liv.ac.uk/~michael/Space05/tsourdos-abs.pdf#search=%22%22cranfield%20university%22%20uav%20team%22>

“Ultraswarm.” Essex University. Modified July 31, 2006. <http://gridswarms.essex.ac.uk/technologies.html>

United States. Department of the Army. “Small Arms Fire Against Air Attack.” United States Army Air Defense Artillery School, May 2006. <http://www.fas.org/man/eprint/sad.pdf#search=%22defense%20against%20uavs%22>

United States. Department of Energy. “Field Testing of Remote Sensor Gas Leak Detection Systems,” December 2004. <http://www.netl.doe.gov/technologies/oil-gas/publications/td/Final%20Report_RMOTC.pdf>

"Unmanned Aerial Vehicles (UAVs)." Global Security <www.globalsecurity.org/military/world/china/uav.html> (Accessed 10/24/2006).

"Unmanned U.S. Plane Shot Down Over Iraq." Public Broadcasting System News, December 23, 2002. <http://www.pbs.org/newshour/updates/iraq_12-23-02.html>

Unmanned Vehicle Handbook 2006. Bucks, United Kingdom: The Shepard Group, December 2005.

"USF Deploys Unmanned Aerial Vehicles to Katrina Rescue Operations," September 7, 2005. <http://www.sciencedaily.com/releases/2005/09/050908081119.htm>

Vandermeersch, B.R.R., Q.P. Chu, and J.A. Mulder. "Design and Implementation of a Mission Planner for Multiple UCAVs in a SEAD Mission." AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005 (AIAA 2005–6480).

Van Persie, M., A. van der Kamp, and T. Algra. "Simulation and Optimisation of an Optical Remote Sensing System for Monitoring the European Gas Pipeline Network." National Aerospace Laboratory NLR, Netherlands. <http://www.uavm.com/images/UAV_Gas_Pipeline_Inspection.pdf>

Vladykin, Oleg. "Unmanned Aerial Breakthrough." MIGnews.com.ua Web site, October 24, 2006 <http://mignews.com.ua/en/articles/213361.html> (Accessed October 2006).

Williams, Sally. "Welsh Team Plans Pilotless Aircraft for Hi-Tech Crop Watch." *Western Mail* [Cardiff, Wales], July 25, 2006 (via ProQuest ID: 1082745911).

Yamaha Motor Company. "Agricultural Applications." <http://www.yamaha-motor.co.jp/global/industrial/sky/agricultural/index.html>

Yamaha Motor Company. "Atomic Power Plant Surveillance." <http://www.yamaha-motor.co.jp/global/industrial/sky/solution/atom/index.html>

Yamaha Motor Company. "Infrastructure Maintenance." <http://www.yamaha-motor.co.jp/global/industrial/sky/solution/infrastructure/index.html>

Yamaha Motor Company. "Plant Growth Survey/Rice Paddy Remote Sensing." <http://www.yamaha-motor.co.jp/global/industrial/sky/solution/plant/index.html>

Yamaha Motor Company. "Volcanic Observation." <http://www.yamaha-motor.co.jp/global/industrial/sky/solution/volcano/index.html>

Zhang, Xiao, and Fang Jiancheng. "A Design of Low Power, High Capability GNC System of Micro Unmanned Aerial Vehicle." AIAA Guidance, Navigation, and Control Conference and Exhibit, August 15–18, 2005 (AIAA 2005–6285).